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VOLUME 9 SEPTEMBER, 1933 NUMBER 3

SOME MEASUREMENTS OF THE ELECTROSTATIC PROPERTIES OF PHOTOGRAPHIC FILMS[1]

BY D. C. ROSE[2]

Abstract

This paper deals with experiments performed to determine the electrostatic properties of celluloid camera films. The information derived was used in attempts to eliminate marks due to static electricity on film used in aerial photography.

Camera films were rubbed with wool or brass and the resulting electrostatic effects studied. The required atmospheric conditions were reproduced by carrying out the experiments in a tank in which pressure, temperature and humidity could be controlled independently. It was found that the charging effect was more pronounced in a moist than a dry atmosphere.

Methods of eliminating the trouble caused by static electricity in aerial photography are discussed.

A study has been made of the amount of static electricity generated when pieces of celluloid camera film were rubbed by various materials under different atmospheric conditions. The object of the investigation was to try to eliminate the generation of static electricity in cameras used for aerial photography. The discharge resulting from such static charges marks the film, often so badly that it is useless for mapping or survey work, making it necessary to re-photograph large areas.

The problem of the prevention of marks on films due to electrostatic charging was undertaken from two points of view, first, a study of the conditions under which the film was used in the aerial camera (this involved a study of the atmospheric conditions under which photographic flights were made); and second, a study of the electrostatic charges acquired by celluloid films when subjected to atmospheric and other conditions approximating those under which it is used in practice.

I. Process of the Charging of the Film as it Moves Through the Camera

Celluloid, which seems to be the only satisfactory material from which photographic films can be made, has the great disadvantage that it acquires electrostatic charges very readily.

[1] *Manuscript received July 27, 1933.*
Contribution from the Physics Division, National Research Laboratories, Ottawa.

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In cameras used for aerial mapping in Canada (size of picture, $7\frac{1}{4}$ x $9\frac{1}{4}$ in.) the film, while exposure is being made, is clamped between a glass focusing plate and a bare metal or felt covered pressure plate. Between exposures the pressure plate is raised slightly so that the film may be rolled on to the next position of exposure. In rolling the film through between the pressure plate and the focusing plate, rubbing on either or both plates cannot be avoided. The process of building up a charge on the surface of the film, sufficiently intense for a spark to jump, depends on so many factors about which so little is known that it is difficult to say exactly where and how the charge is formed. However, an insulating material, *e.g.*, a celluloid film, moving over a piece of felt or metal or a glass plate, such as the pressure plate and focusing plate of the Fairchild aerial camera, creates ideal conditions for the generation of electrostatic charges. Whether or not charges will be generated of course depends somewhat on whether or not the film is charged when it first comes off the roll. If there were no electrostatic charges on the film in the roll, the building up of charges as it moves through the camera would be less likely than if it were charged originally. The experience of the writer is that celluloid is one of the most difficult of insulating materials to keep discharged. Handling of any sort whatever seems to cause it to acquire electrostatic charges. From experience of electrostatics in general one would say that the film should be wound and kept in as moist a condition as possible without spoiling the sensitivity of the emulsion. In fact such a procedure has been recommended. However, the results of recent experiments indicate that the charging effect appears under certain conditions to be greater with the film in a moist atmosphere than in a dry one. The moisture would be expected to cause the static charge to be dissipated or conducted away without a spark while the film is rolled up on the spool but until a more complete investigation is made, this point remains unsettled.

Even if the film is totally discharged when it leaves the roll, it may acquire a charge by rubbing either on the glass plate or on the pressure plate. If it is charged on the roll, the effect of rubbing will likely be magnified. Such charges can easily raise the potential of the film sufficiently high to cause a spark to jump along the surface of the film when it has passed between the pressure plate and the glass plate. This spark appears to jump to the roller or to the metal strip holding the glass plate in place, depending on which side of the film is charged. It jumps along the surface of the film causing the static markings which look somewhat like lightning discharges or a combination of these lightning flash marks and a diffuse black spot (see Plate I, Fig. 1). Fig. 1 is a reproduction of a piece of film used in an aerial camera. The flashes caused by the spark will discharge a band of the film a short distance ahead of the point to which the spark jumps. There will not be another flash until the film has moved on to a point where there is another charge close enough to the roller, or edge of the glass plate, to cause a spark to jump to the metal parts. This accounts for the somewhat regular lines of discharge across the direction of motion of the film. These sparks along the edge of the glass plate may be seen if the film is rapidly rolled through the camera outdoors on a dark dry winter night.

FIG. 1. *Static markings on film used in aerial photography.*

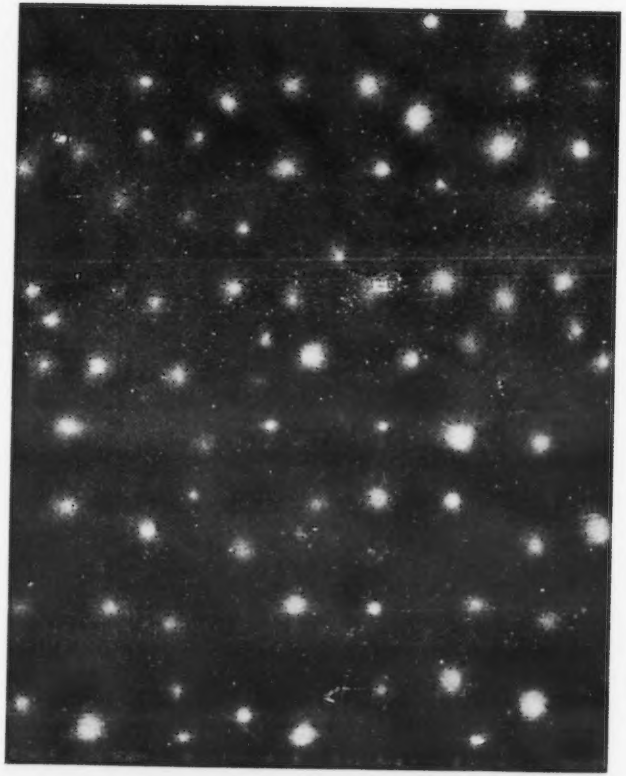

FIG. 2. *Static markings on film used in aerial photography.*

PLATE I

Sparks were also seen to jump from one part of the film to another where it comes off the roll. Such sparks would make the round diffuse static marks shown in Plate I, Fig. 2. This type of spot also occurs when sparks jump from the film to other parts of the camera. This also indicates that the film observed by the writer was charged in the roll. From this it need not be inferred that new films are charged in the roll, as the films used for experimental purposes were spoiled films which had been re-rolled a number of times.

II. Experimental Study of the Charging of Celluloid Film

Preliminary Experiments

In view of the probability of charges being generated as the film passes over the pressure plate, some preliminary tests were made on the relative charging of a piece of film rubbed by different substances. A piece of film, sensitive side down, was clamped on a flat brass plate electrically insulated and connected to an electrostatic voltmeter. The surface of the film was given a number of vigorous rubs with various materials and the deflection of the voltmeter noted when the material was removed. Care was taken that the amount and nature of the rubbing should be approximately the same for each reading. The following materials were used:—celluloid plate, another piece of film, brass plate, wood (white pine), wood-fibre board, wool felt, cardboard, silk, piece of film rubbing with emulsion surface. These materials are listed in such an order that the first gave most charging effect and the last the least. The experiments were performed in the summertime at ordinary room temperatures. The results were fairly consistent when repeated, though the relative positions of some of the materials might change a place or two. The same piece of film was used throughout this experiment. The results of Shaw and Hanstock (6) in experiments on frictional electricity indicate that the electrostatic properties of materials change with continuous rubbing due to distortion of the surface. The film going through the camera would constantly offer a new surface to be rubbed; consequently the result might be different. One would not expect, however, that the order of the above list would change much.

These initial results indicate that the pressure plate should be covered with a piece of undeveloped film with the face or emulsion side exposed. Probably a piece of exposed and developed film would do just as well, as the surface would be black. Such a surface would have to be replaced periodically but should last several months.

To make a more complete study of the electrostatic charging of films under various conditions, it was decided to measure the humidity and other properties of the atmosphere under actual operating conditions. The Royal Canadian Air Force undertook to give the writer a number of flights to measure temperature, relative humidity, and quantity of electric charge in the air under conditions similar to those found in photographic work. Four flights were made, the results of which have been published (4, 5).

It was found that at certain levels humidities up to 80 or 90% might easily be encountered, while the relative humidities at lower and at higher altitudes were considerably less. The height of this level of maximum relative humidity varies with the weather but appeared to be 1,000 to 2,000 ft. above the level at which clouds form when there are such clouds in the sky. During the flights clouds were avoided as much as possible. The difference between the cloud level and the height of the maximum relative humidity level may have been due to the position of the instruments in the slip stream. This has been discussed (4). An incidental result of these observations was the discovery that the hair hygrometer is a very unsatisfactory instrument for aircraft work.

The results of the observations on the electricity or ion content of the air have been published (5). The most striking feature was the fact that a maximum appears in the excess of positive over negative electricity in the air at the same altitudes as the relative humidity maxima (2). The observations on the electric space charge in the atmosphere were taken more because of the excellent opportunity offered in the flights to obtain information on atmospheric electrical effects, than for any significance they might have on the static charging of the film in aerial cameras. It would be contrary to expectations to find that the relatively small electric charge in the atmosphere outside a completely enclosed metallic box like a camera could have an effect on the electrostatic charging that is going on inside the box. This, of course, assumes that the various parts of the complete camera, cone, magazine, and other parts, are not insulated from one another. Further, it would not be expected to matter whether or not the metallic camera itself was electrically connected to the frame of the aeroplane. These parts in cameras examined by the writer were not insulated.

The humidity, on the other hand, and the temperature would be expected to have some effect because, although the camera is effectively a completely enclosed conducting box, it is not air-tight and changes in humidity outside would gradually work into the magazine.

Apparatus with which Observations were made on the Charging of Films under Conditions Similar to Those Found in Flight

To reproduce conditions under which effects of static charges appear in photographic flights, a tank was built in which the pressure, temperature and humidity could be controlled. The tank was cylindrical in shape, with flat removable heads. It was lined inside with coils of copper pipe through which cold brine from a refrigerating machine could be pumped.

Attached to one head of the tank was an apparatus in which a piece of film or other material could be clamped to a flat brass plate 3 in. square. This brass plate was supported on insulated posts and a lead was taken out through the head of the tank, to be connected to an electrometer. Above the brass plate was another brass plate parallel to the insulated plate, to which the rubbing material was fastened. This plate was supported by its centre from

a carriage which ran on two rails (see Fig. 3). The support was so arranged that the plate was free to tilt slightly in both directions, so that when pressed down on the lower insulated plate it would adjust itself to make maximum contact with the film. The rails carrying the carriage supporting the rubbing plate could be raised and lowered by a parallelogram link motion controlled from outside the tank. The rubbing plate was moved back and forth by a crank and connecting rod, also controlled from outside the tank. The rubbing plate was pressed onto the insulated plate by a spring which was calibrated, so that the pressure was known. The rubbing plate was $4\frac{1}{2}$ by 3 in. and the crank motion had a stroke of $1\frac{1}{2}$ in., so that the insulated plate was completely covered by the rubbing plate at all positions of the crank.

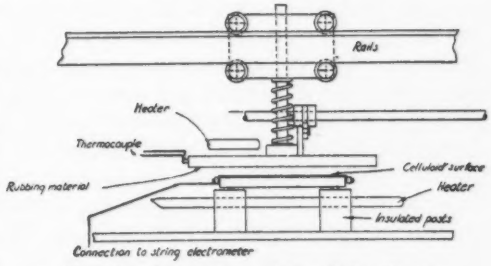

FIG. 3. *Apparatus used for rubbing film to produce electrostatic charge.*

Two electric heaters were placed as shown above the rubbing plate and below the insulated plate. These were used in conjunction with the cooling coils on the tank to produce rapid changes in temperature. The temperature of the rubbing plate was measured by a thermocouple attached to the plate itself, as shown. The temperature of the insulated plate could not very well be measured and still retain the required insulation. However, the heaters and other parts were arranged in so far as possible so that the two plates should warm up and cool down at about the same rate. Possible effects due to temperature differences will be discussed later.

Supported on the other head of the tank was an electric fan to circulate the air, a glass window through which to observe the inside of the tank and a dew point hygrometer for measuring humidities. The hygrometer was hung well out in the tank in front of the window so that the dew point could be observed through the window. The temperatures were measured with thermocouples and a Wolf potentiometer. A platform in the centre of the tank supported a tray of the drying agent or humidifying agent employed.

Procedure

The charging of a piece of film when rubbed by, say, a piece of felt, would be expected to depend on a number of variables. An experimental procedure in studying the charging effect should attempt to fix all but one. The variables concerned in this investigation were temperature, humidity, pressure, rate of rubbing, amount of rubbing, and pressure of rubbing material on the film. The last three, rate of rubbing, the amount of rubbing, and pressure of the rubbing material on the film, were expected to be of secondary importance, as others who have experimented on the electrostatic charges between two substances have found that the charge produced is independent of these variables.

Macky (3) finds that on rubbing such substances as aluminium and sulphur, the charging effect is independent of the normal pressure between the specimens, the velocity of rubbing and the amount of rubbing, provided it is over a certain amount. Macky and others (Kluge (2), Wolf (8), and Jones (1)) using various types of apparatus and materials, usually an insulator and a conductor, show curves, giving amount of charging plotted against amount of rubbing, which indicate that the amount of charging first increases rapidly with the amount of rubbing, then slowly approaches a steady value independent of the amount of rubbing. In the present experiment the same appeared to be the case, though the point was not investigated very thoroughly. The amount of charging of the celluloid when rubbed by brass or felt was found to be independent of the rate of rubbing and of pressure on the plate, in further agreement with other electrostatic experiments.

However, during any run in which temperature, humidity or air pressure variations were being recorded, precautions were taken to turn the crank the same amount, usually one to five turns, depending on conditions, and at the same rate and with the same pressure between the rubbing plates (usually in the neighborhood of 1200 gm. total pressure).

A fibre electrometer was used to measure the voltage produced by the charge on the celluloid. This instrument was found very satisfactory in that its sensitivities could be varied greatly to observe widely different conditions, and the instrument was quite rugged and not easily disturbed.

The procedure for taking an observation was as follows. First, with the rubbing plate lifted about $\frac{3}{4}$ in. away from the celluloid covered plate, the electrometer was grounded. Then with the electroscope and insulated plate not grounded, the rubbing plate was lowered onto the celluloid. If there were no charge on the material on the rubbing plate or on the celluloid, no deflection of the fibre took place. The crank was then turned the requisite number of times and the rubbing plate was raised from the insulated film-covered plate and the deflection of the electrometer fibre recorded. Then the film was discharged as explained in the following paragraphs. This process was usually repeated three or four times before conditions were changed. The air pressure or whatever variable was being studied was then changed and the process repeated.

Discharging the Films

The obvious way to discharge the surface of the film and rubbing material is to make the air in its neighborhood conducting. In the early experiments with the apparatus, this was done by causing an electric spark to jump from a row of pin points about $\frac{3}{4}$ in. away from the rubbing plate. This should have caused intense ionization, which should have neutralized the charges on the celluloid film and the rubbing material. Care had to be taken to make the spark jump to metal parts away from the rubbing material (felt) or the celluloid; otherwise it would burn. One series of experiments was spoiled by this taking place. The process of discharging the film was to put the spark on for two or three seconds with the plates separated and grounded.

The spark was effective in discharging the celluloid in experiments in which the celluloid was rubbed with a brass plate, but when a more complex material, like felt, was used the spark would not discharge it. In place of the spark a quartz mercury vapor lamp was tried. This was so arranged that an intense beam of ultra-violet light was thrown between the two plates when separated. This should have caused ionization of the air which would have neutralized the charges on the plates. This was also found to be satisfactory in the case of the brass rubbing plate but not in the case of felt. Apparently the felt became charged throughout its volume and the ionized air in the neighborhood would not penetrate it far enough within reasonable time to discharge it. As a result, instead of discharging the felt its charge was corrected for in plotting the observations as follows: the mercury arc was left on for about 30 sec. with the plates separated and grounded, then turned off, the insulated plate and electrometer ungrounded and the plates closed together. This caused a deflection of the electrometer fibre in an opposite direction to that caused by the charged celluloid. This deflection was taken as the zero point for that particular observation. The rubbing was then carried out and the plates separated, the resulting fibre deflection being read. Whether or not this is a true correction for the residual charge on the felt is uncertain, because the residual charge on the felt would have some influence on the charging effect due to the rubbing. However, qualitative results are all that could be expected in the present experiment and a residual charge on the felt should not affect them much.

Results of Observations

Variation with Pressure in a Dry Atmosphere

(a) Felt on Film Back

To obtain quantitatively repeatable results in measurements of electrostatic charging by rubbing is very difficult and in practice is rarely, if ever, achieved. Even when simple solid substances like aluminium and sulphur (3) are used it is difficult to reproduce a given set of readings quantitatively. This is, no doubt, owing to the fact that the charging is an exchange of electricity between the surfaces involved and even slight rubbing cannot take place without altering the orientation or structure of surface molecules. The experimental procedure is to put the surfaces being studied under a cycle of operations and study the results with repetitions of the cycle under various conditions.

The present experiments were limited to a study of the behavior of pieces of Kodak panchromatic film, taken out of a roll as it would be used in aerial photography, when rubbed by a clean piece of black felt or a clean bare brass plate. The film was cleaned carefully by wiping with cotton wool containing petroleum ether. Only the rubbing on the back or the insensitive side of the film was studied. The usual procedure was to reduce the pressure in the tank by steps taking readings at each step, then increasing and reducing it alternately, keeping all other variables (temperature, humidity, amount and rate of rubbing and pressure on plate) constant. Then this was repeated at

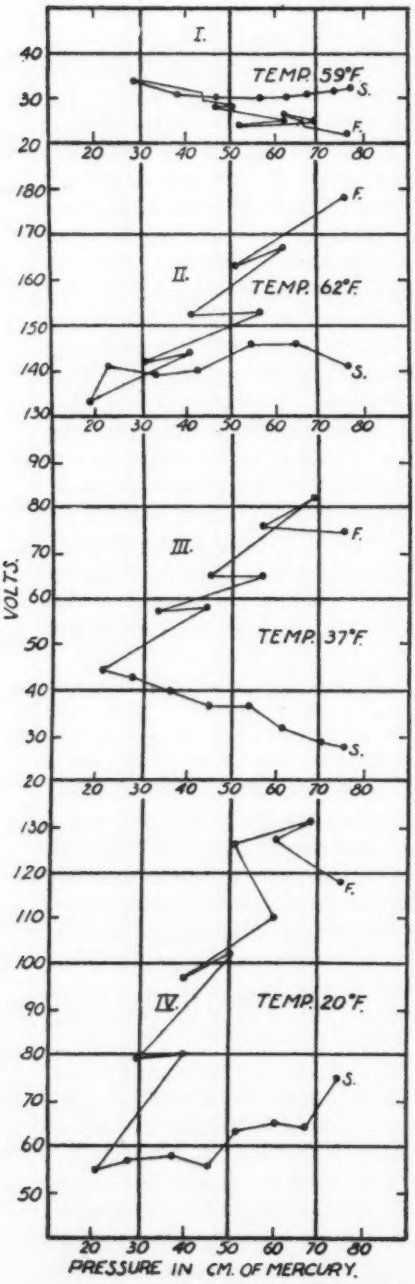

FIG. 4. *Variation of electrostatic potentials with pressure when celluloid is rubbed by felt in a dry atmosphere at various temperatures.*

different temperatures, and later, temperature runs were taken at constant pressures. Then the whole was repeated at different humidities.

Fig. 4 shows the results plotted in volts to which the plate and electrometer became charged. In the case of Curves I, III and IV, the felt was stretched tightly over the plate and held on by clamps at the ends of the plate. This allowed the felt to rub somewhat on the upper plate and it was thought that this caused some of the large residual charge which was so difficult to remove from the felt; hence in later experiments, of which Curve II and curves in subsequent figures are samples, the felt was stuck to the brass rubbing plate by means of a thin layer of cement made by dissolving collodion in amyl acetate. This did not reduce the residual charge in the felt as was expected. In the case of Curves I, III and IV the amount of rubbing corresponded to one turn of the crank. In the case of Curve II the crank was turned five times. The amounts of charging in the two cases are not comparable because of the different mountings of the felt. Each point on these curves is the average of three or four individual observations. The points in the order in which they were taken are joined by a straight line. In cases where the straight lines overlap (Curve I), the line has been made to deviate slightly to make the figure clearer. The most noticeable feature of these results is the fact that while the pressure is being reduced the charging follows no particular rule, but when the pressure is increased, a greatly increased charging effect usually results. A subsequent reduction in pressure either leaves it constant or reduces it slightly and an increase in pressure

again increases the charging. This is particularly so at low pressures and may reverse near atmospheric pressure. It is also more noticeable at low temperatures than at high, as other curves at temperatures between 60° and 65° F. did not show it, though in Curve II it does appear.

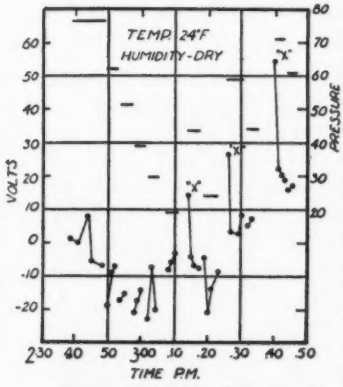

FIG. 5. *Variation of electrostatic potential with pressure. The pressure at which each observation was taken is indicated by the heavy bar above it.*

Later observations, particularly those at low temperatures, indicated a systematic short period change in the charging effect which is indicated in the curve in Fig. 5. In this curve each individual observation is indicated, so that the horizontal axis represents the time at which the observations were taken, the pressure being indicated by the short horizontal bars and the scale on the right side of the figure. The pressures are indicated in centimetres of mercury. As the pressure was reduced the charging decreased slightly and then increased slightly again in a manner not unlike that indicated in the curves in Fig. 4, but when the pressure was increased, a great increase in the charging effect (see point "X") was noted. This effect is analogous to the increased charging with rising pressure in Fig. 4, but is different in that it appeared for the first rub only. An average of the observations at each pressure would not show the effect nearly so pronounced. This effect appeared only at the lower temperatures observed.

A satisfactory explanation of this temporary increase in charging effect has not been found. When it was ascertained that the quantity of charge developed was so sensitive to humidity (see later paragraphs), it was thought that owing to the air from the room being inadequately dried before it entered the tank to raise the pressure, the moisture carried into the tank caused the temporary increase in charging before it was absorbed by the calcium chloride. However,

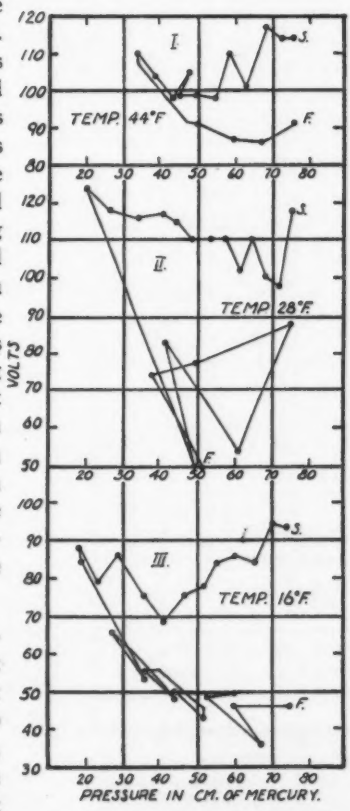

FIG. 6. *Variation of electrostatic potentials with pressure when celluloid is rubbed with a bare brass plate in a dry atmosphere at various temperatures. S = beginning of run, F = end of run.*

the fact that this temporary increase in the quantity of charge also appeared with increasing pressure when the tank was kept at a humidity of about 60%, indicates that it was probably due to some other adsorption phenomena. This point requires a more detailed investigation before more definite conclusions can be drawn.

(b) Brass on the Film Back

Fig. 6 shows the results of experiments in which a smooth, clean, bare, brass plate was used to rub the film in a dry atmosphere at varying pressures and temperatures. The figure indicates that, as before, the variation in the charging effect as the pressure is reduced is not very great and seems to follow no definite rule, but when the pressure is increased a sharp decrease in the charging takes place. This is particularly noticeable at low pressures (about 20 to 50 cm. of mercury) and more noticeable at low temperatures than at high ones. It should be noted here that this change in charging effect with increasing pressure is in the opposite direction to that observed when felt is used as the rubbing material. Also the charge acquired by the celluloid is much greater when rubbed by bare brass than when rubbed by felt. This is consistent with the early rubbing experiments described in Part I.

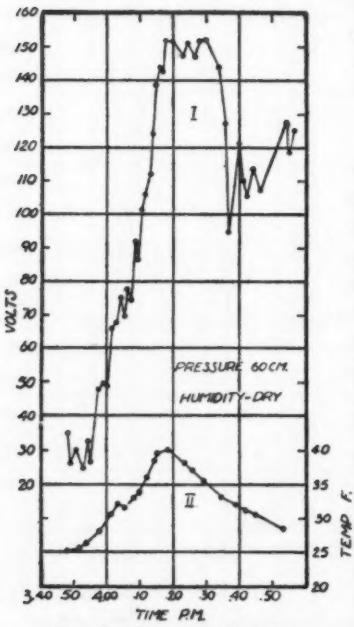

FIG. 7. *Variation of electrostatic potential with temperature when celluloid is rubbed with felt in a dry atmosphere. The temperature at which each observation was made is indicated by the part of the temperature curve directly below the point concerned.*

Variation with Temperature in a Dry Atmosphere

(a) Felt Rubbing Plate

The curves shown in Fig. 4 for felt rubbed on celluloid indicate no regular variation of the charging effect for runs at different temperatures, but as stated above they are not entirely comparable as they do not represent a continuous series of runs using the same sample throughout. When all pressure runs at various temperatures are examined together, it is seen that there is a tendency for the mean charging to be lower at lower temperatures. This is also indicated by several runs which were taken at a constant pressure and varying temperature. Fig. 7 shows the results of such a run at a pressure of 60 cm. of mercury. The charging effect rises with the temperature, being several times greater at 40° than at 25° F. A subsequent reduction in temperature does not cause a reduction in charge corresponding quantitatively, but does reduce it considerably. In another run, the day before, starting at 60° F. and decreasing the temperature to about 28° F. the charging effect was reduced from about 60 volts to only four or five volts, the

reduction varying roughly linearly with temperature. No discontinuity was noted as the temperature passed through freezing point.

(b) Brass Rubbing Plate

When a bare brass rubbing plate was used the variation with temperature, other variables being fixed, was in the same direction as the variation observed when a felt plate was used, but less pronounced.

Variation with Humidity

(a) Felt Rubbing Plate

Time did not permit of an extensive study of the electrostatic charge acquired by celluloid at many different humidities. This was owing to the difficulty of varying the humidity rapidly and accurately in the closed tank, where other variables must be kept under control. The result is that observations were made only in a dry atmosphere (all the results described previous to this were taken in a dry atmosphere) and with a saturated solution of sodium bisulphate in dishes in the tank. In these experiments the fan installed in the tank kept the air in constant circulation, so the humidity should have been uniform. International Critical Tables give the relative humidity over a saturated solution of $NaHSO_4.H_2O$ as 52% at a temperature of 20° C.

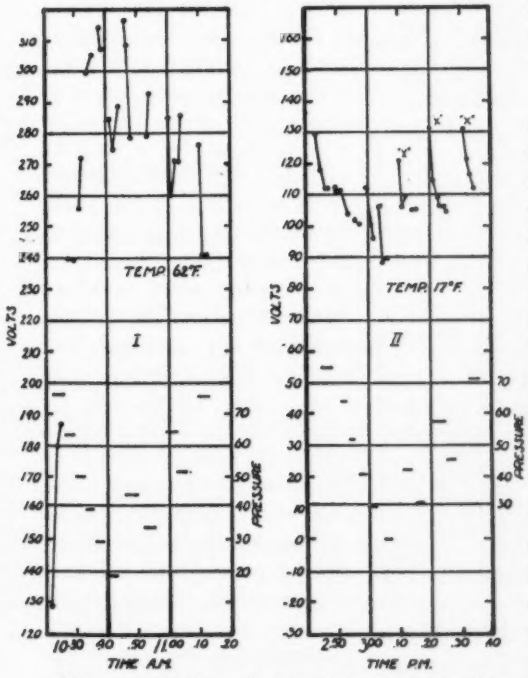

FIG. 8. *Variation of electrostatic potential when celluloid is rubbed with felt in a moist atmosphere. The pressure at which each observation was taken is indicated by the heavy bar above or below it.*

The most surprising result of rubbing the film with felt or brass was the greatly increased charging effect. The voltage to which the celluloid became charged when rubbed in this moist atmosphere was usually two or three times that found in a dry atmosphere. Fig. 8 shows pressure curves at 62° and 17° F. The curves are plotted in a similar manner to that of Fig. 5 and should be compared with it. The humidity, according to tables, at a temperature of 62° F. should be about 50%. Actually the dew point hygrometer indicated a slightly higher relative humidity. At the lower temperature the dew point hygrometer indicated a relative humidity of 65%. It will be observed that the increase in

charge for the first rub after the pressure has been increased is very noticeable at the lower temperature (points marked "x") and not at the higher. This is similar to the observations in a dry atmosphere.

Fig. 9 shows the effect of temperature variation with other variables fixed (pressure 75.4 in case of Curve I and 56.6 cm. for Curve II) and a saturated solution of sodium bisulphate as a humidifier. The humidity, of course, will vary with the temperature and pressure. The curves indicate that the charging effect tends to rise with dropping temperature at pressures near ground pressures (Curve I), while at reduced pressure the charging continues to increase through a rising and falling temperature cycle (Curve II). It would require a considerably more extensive investigation to be sure of the temperature effect.

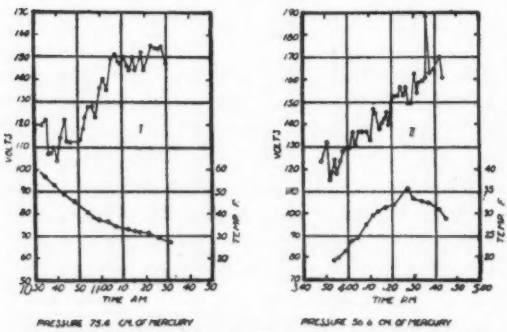

FIG. 9. *Variation of electrostatic potential with temperature when celluloid is rubbed with felt in a moist atmosphere. The temperature at which each observation was made is indicated by the part of the temperature curve directly below the point concerned.*

(b) Brass Rubbing Plate

When a bare brass rubbing plate is used the results in a humid atmosphere are consistent with those obtained in a dry atmosphere, in that the charging effect is much greater (two or three times) than when the rubbing plate is covered with felt. The amount of charging seems to lessen with reduced temperatures as indicated by a curve not shown, but a temperature cycle (Fig. 10, Curve II) shows no consistent variation as in the case of felt. Fig. 10, Curve I, shows a pressure run at a temperature of 26° F., relative humidity about 65% at atmospheric pressure. The increased charging on increasing the pressure is not noticeable in the case of the brass rubbing plate. The most noticeable feature of the results with a brass rubbing

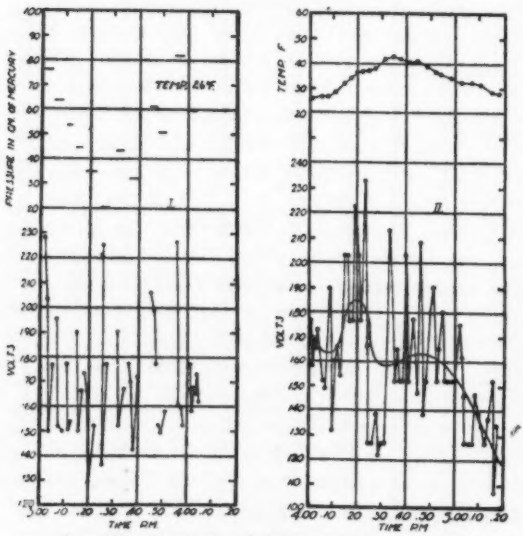

FIG. 10. *Variation of electrostatic potential with temperature and pressure when celluloid is rubbed with brass. The pressure or temperature at which each observation was taken is indicated by the heavy pressure bars or the temperature curve immediately above the point concerned.*

plate in a humid atmosphere is that the observations are much more irregular than under the other conditions observed. In Curve II a mean curve is drawn through the many points observed but points occur a considerable distance away from it. A pressure run at 69° F. is very similar in form to Curve I, Fig. 8.

Direction and Quantity of Charge

The actual quantity of charge was not measured though the capacity of the insulated system is estimated to be 30 to 35 microfarads. Thus a charge which raised the potential of the electrometer to 100 volts would represent about 3×10^{-9} coulombs of electricity. The charge represents that induced in the electrometer by the charge on the upper surface of the celluloid. The charging was usually of the same sign as that produced when an ebonite rod is rubbed with felt, *i.e.*, negative electricity. In the curves shown the positive voltages represent the usual nature of the charge on the celluloid, *i.e.*, negative electricity. On some occasions when felt was rubbed on the film back the sign of the charge was reversed. Such points are shown as negative voltages (see Fig. 5).

Summary of Results

Owing to the nature of these experiments and the material under investigation, the results can lead only to a qualitative analysis of what happens. The qualitative summary is given below and later the application of the results to aerial cameras, in so far as they are applicable, will be discussed.

1. *Rubbing Materials*

Of the two rubbing materials tried, a bare brass plate left the celluloid film charged to a potential two or three times higher than that when the rubbing plate was covered with felt.

2. *Variation of Charging with Pressure*

(a) Felt covered rubbing plate. The variation of charging with pressure reduction followed no definite rule. A steady decrease in pressure from about 76 to about 20 cm. of mercury usually caused small changes (not more than 25 to 40%) in the quantity of charge when the atmosphere was dry (see Figs. 4 and 5). In a humid atmosphere very large changes are likely to occur but these follow no definite rule (see Fig. 8). The most significant feature of pressure variation was the fact that when the pressure is rapidly increased, say, by about 15 cm. of mercury, the quantity of electric charge produced increased considerably but often only the first time the film was rubbed (see Figs. 5 and 8). This phenomenon was particularly noticeable below about 60 cm. of mercury and sometimes was reversed in sense at higher pressures. It also occurred more noticeably at low temperatures than at high.

(b) Brass as rubbing plate. The variations in the quantity of charge with pressure are analogous to those in the experiments in which celluloid was rubbed with felt, except that there was a marked decrease instead of an

increase in charging when the pressure was increased (see Fig. 6). Again this appeared only at pressures below about 60 cm. and was more noticeable at low temperatures than at high. In a moist atmosphere this effect seemed either to be absent or to occur in opposite sense (see Fig. 10).

Temperature Variation

(a) Felt as rubbing plate. In a dry atmosphere the quantity of charge in general increased with the temperature over the range studied (about 25° to about 65° F.) (see Fig. 7). In a moist atmosphere the quantity of charge did not appear to follow any definite rule with varying temperatures (see Fig. 10).

(b) Brass as rubbing plate. In a dry atmosphere the quantity of charge decreased slightly with temperature. In a moist atmosphere it was very erratic and appeared to follow no definite rule (see Fig. 10).

Variation with Humidity

Apart from variations discussed in the two sections above, the most significant fact appearing in the results of these observations was that the quantity of charge generated was greater in a moist atmosphere than in dry, usually by a factor of two or three.

Conclusions

The most striking facts derived from the above results are the effects of increasing the pressure and the humidity. Obviously the triboelectric effect of celluloid film is intimately associated with the atmosphere in which it is rubbed. The same probably applies to felt and brass, as the effect of increasing pressure in dry air is opposite in the two cases. The unexpected increase in quantity of charge generated in a moist atmosphere also indicates that the layers of gases and vapors on the surfaces of the materials have a profound influence on the triboelectric effects.

Other investigators (1, 4, 5, 7, 8) also find that the triboelectric effect observed on rubbing various materials such as ebonite, silk, glass, quartz, sulphur and various metals depends to a great extent on the gas surrounding the specimens. The variations found by different authors however cannot be compared because of great differences in experimental method and combinations of materials used.

Before discussing the application of the above results to the reduction of the static markings on films, let us consider as nearly as we can the conditions under which the films are used in practice in Canada. The temperature of the outside air under photographic conditions is usually somewhere between about 15° and 40° F., though it might vary even more. If a cabin plane is used, which is often the case, the film magazines are kept in the cabin which is heated perhaps to a temperature 20 or 30 degrees higher than the outside air. The camera, on the other hand, being partly inside the cabin and partly outside will be at some intermediate temperature below the temperature of the film magazine. Thus when the film is unrolled and passes over the focusing plate it may be subjected to a sudden temperature reduction. According to

the above results, if the humidity were zero a drop in temperature should tend to reduce the tendency to electrostatic charges. However, the humidity will not be zero. There is a certain amount of moisture in the film when it is rolled up and further, if the plane is flying at a level where the relative humidity is high, the humidity in the film magazine would tend to be medium or high. To obtain a significant measure of the humidity near the surface of the film in a camera under operating conditions would be difficult, but it would not be unexpected to find it considerably above 50%. Under these conditions the effect of a temperature drop remains uncertain but might easily enhance charging. The pressure during a photographic flight would not be expected to change very much unless considerable changes in altitude took place, which as far as the author knows is not the usual practice. The slow reduction of the pressure on ascent from ground, combined with a reduction in temperature, might well cause a great enhancement of the charging effect as indicated by Fig. 8.

These observations, of course, are based on experiments with a rubbing plate of either felt or bare brass. In some of the older cameras felt was used but in newer models the pressure plate was covered with an electrically conducting black paint. The effect of rubbing a film with such a painted plate was not studied. A further difference between laboratory experiments and practice was that in practice new film is constantly being brought under the so-called rubbing plate, while in the laboratory the rubbing was done on the same piece of film throughout a series of runs. It is well known that the effect of rubbing changes the electrostatic characteristics of the surface of the film. It was intended that if the results of the above experiments in the tank indicated definitely conditions under which charging did and did not take place, further experiments would be performed requiring more elaborate apparatus and much more time. For instance, fresh film could be used for each point under observation. Further, the front, or sensitive side of the film, also has electrostatic properties which are responsible to some extent for static markings. The results of the experiments that have been done indicate that under practically any conditions the celluloid is liable to acquire a considerable electrostatic charge when rubbed, and that the charging is particularly sensitive to changes in physical conditions of the film and atmosphere.

III. Possible Methods of Reducing Static Marks on Films

1. *Choice of Atmospheric Conditions*

From the results of the laboratory experiment on rubbing felt and brass on celluloid films it is evident that the atmospheric conditions in which static is least likely would be the dryest and coldest available. The observations on relative humidity of the atmosphere described previously (2) indicate an altitude slightly above the cloud level, at which the relative humidity is a maximum. Such a maximum appears to exist even on cloud-free days. If flying at this level during photographic operations could be avoided a reduc-

tion in static might be found. If there are any scattered clouds in the sky the altitude can be determined easily from the cloud level. The undesirable region is from the level of the base of the clouds up to about 2000 ft. higher.

However, as discussed in the last paragraphs of the previous section, the applicability of these results is somewhat uncertain as the history of the film immediately previous to exposure is important. Keeping the film magazines at the temperature of the camera, that is, not heating the cabin where they are kept, in fact, keeping them as cold as possible might be advisable—though, unless the air in the magazine is dry, low temperatures are of doubtful value.

2. *Process of Rolling and Loading the Film*

It was suggested that with a view to reducing charges of static electricity the film should be used in as moist a condition as possible without danger of spoiling the sensitivity of the photographic emulsion. The results of the laboratory experiments indicate that the film back is more likely to acquire charges when in a moist atmosphere than in a dry one. However, there are two effects involved, (1) the actual source of the electrical charge, and (2) the dissipation of the said charge without a spark. If the film were very moist the water which adheres to the surface of the celluloid would make it more or less an electrical conductor and hence the charge might be dissipated without leaving the objectional marking on the photograph. Without considerably more experimental work, it is impossible to say what humidity would be required to make the surface conductivity sufficiently great to remove the possibility of charges building up sufficient potential to mark the film. Very high humidities (near 100% relative humidity) would no doubt solve the problem but such humidities would probably also shorten the life of the photographic emulsion unreasonably.

3. *Conducting Film*

The ideal way to entirely eliminate static markings is to make a film which is an electrical conductor. During a consultation with engineers of the Eastman Kodak Company, the author was informed that they have been trying for years to produce a conducting film, without much success. If it were not necessary to use a transparent film the problem would not be so difficult. For instance, if the emulsion could be put on a thin steel ribbon instead of celluloid, no static whatever would be found. However, the process of making prints would have to be completely altered because of the opaque film. Reflected light would have to be used. No doubt there would be many other difficulties to be overcome, but even if steel were found to be entirely unsuitable, probably some conducting material could be found just as suitable as celluloid except for transparency.

It is understood that the Fairchild Aerial Camera Corporation has carried out experiments in which a sheet of metallic foil is wound on the film spool with the film and runs through the camera back of the film, so that no appreci-

able rubbing takes place on the film back. This should remove static markings due to charges on the film back. No information as to whether sufficient tests have been made to draw any conclusions has been made available.

An alternative suggestion is, that instead of backing the film by a metal sheet a series of fine metal wires be imbedded in the celluloid film so that the charges accumulating on the film would have a much shorter path over the surface of the film before being dissipated by conduction to the camera.

4. *Covering on the Pressure Plate and other Surfaces at which Static Arises*

In Section 1 of this paper some preliminary experiments were described which indicate that probably the best material with which to cover the pressure plate is the emulsion side of a piece of film of the type used in the camera. The Fairchild Aerial Camera Corporation, acting on the results of such experiments brought out static eliminating adaptors for their cameras. The adaptor is a cover for the pressure plate and appears to be a piece of black celluloid with edges molded so it can be slipped over the plate and stay in place. Combined with these were insulated covers for the two aluminium strips which hold the glass focusing plate in place and rollers made of some electrical insulating material, such as bakelite. The object of these was to cover with insulating material the metal parts to which sparks were likely to jump, as described in Part I of this paper.

The Department of National Defence used some of these static eliminators in test flights and in operations in 1931. They very kindly sent a copy of their analyses of static encountered in R.C.A.F. Photography, 1931, to the National Research Council. A summary of their analysis is made in Table I, which also includes other appliances supplied by the National Research Laboratories. Totalling all static troubles one finds that with no eliminators 17.6% of the rolls of film were affected. With the Fairchild static eliminators only

TABLE I

SUMMARY OF RESULTS OF STATIC ELIMINATORS USED IN 1931

Camera equipment	No. of rolls showing effect indicated				Total no. of rolls	Remarks
	Nil	Slight	Medium	Considerable		
Ordinary	909	101 9.2%	51 4.6%	42 3.8%	1103	17.6% affected by static
Fairchild eliminator	75	1 1.2%	1 1.2%	5 6.1%	82	8.5% affected by static
Insulated rollers	2	1			3	
Non-insulated rollers	1				1	
Radium	2				2	

8.5% of rolls used were affected. This indicates about 50% reduction in the total number of rolls affected by static. The reduction was mainly in the rolls which had only slight or medium quantities of static, but under conditions where considerable static (see Column 5) was found there is no reduction but an increase in the percentage of static. The increase may not be significant but it does appear that under bad static conditions the Fairchild eliminators are not successful, though the reduction of the total quantity of static is a step in the right direction and the Fairchild static eliminators on the whole represent an improvement.

5. *Alterations in the Design of the Camera*

Probably the most effective alteration in camera design would be to raise the pressure plate higher and raise the rollers somewhat as well, so that the film would not touch either the pressure plate or the glass focusing plate. As the film curls towards the focusing plate at the edges probably the clearance between the level of the bottoms of the rollers and the glass plate need not be as great as that between the former and the pressure plate. The pressure plate should be raised as high as possible.

In most of the films having static markings, static rarely appears along the edge of the film but is usually concentrated in the centre, the two inches along the edge being relatively clear. Other devices such as the roller on the cam controlling the mechanism which adjusts the distance the film moves, would probably be better placed near one edge and made as small as possible.

Another alteration which has been tried is in the rollers which guide the film in passing under and out from the pressure plate. Two pairs of rollers were made according to Fig. 11. These were sent to the Department of

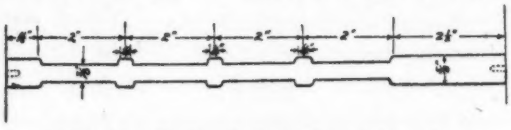

FIG. 11. *Static reducing roller tried in the Fairchild aerial camera.*

National Defence to be tried in film magazines. The rollers were made of aluminium. One pair was coated with a thin layer of celluloid made by dissolving a clean piece of film in amyl acetate and painting several coats of it on the rollers. The other pair was left bare. It was thought that by this means the static markings due to sparks jumping to the rollers might be reduced to the few points where the film touches the roller. This might in some cases save retaking the pictures as a much smaller area of the picture would be spoiled. These rollers have not been given sufficient tests, as only three rolls of film have been used in magazines equipped with the celluloid-coated rollers and one roll in a magazine equipped with the bare aluminium roller. Of these only one roll showed any static and this appeared only in lines where the shoulders on the rollers touched the film. In this case the rollers used were those coated with celluloid.

6. *Ionization of the Air in the Camera*

The object of ionizing the air in the camera is to make it electrically conducting so that any charges generated electrostatically will be dissipated without a spark. The difficulty is that any source of ionization in the film magazine is likely to be a source of light which would spoil the film. Radioactive material like radium might be put in the camera at chosen points so that sufficient ionization would be produced without spoiling the film as it moved through the camera. This was tried. A small quantity of radium (about 0.065 mg.) was suitably placed on an aluminium strip which was fastened to the edge of the pressure plate so that it was immediately over the film as it came out from under the plate. Tests were made to see that the quantity of radium was not sufficiently great to mark the film. If the film were left standing still in the camera for 10 min. or more a faint mark on the film appeared at the edge of the pressure plate. This would not spoil a picture. If the film were rolled through the camera as rapidly as is the custom in practice, no appreciable marking appeared.

The magazine equipped with radium was used only on test flights and only two rolls of film were exposed in it, neither of which showed any static markings; hence there is not enough evidence to say anything about its success.

Another method of ionizing the air in the magazine would be to employ the brush discharge or corona discharge which comes off point electrodes charged to a high potential in air. Such equipment is used in printing presses and weaving machinery to prevent trouble due to charges on the paper or threads.

The brush discharge neutralizer has the disadvantage that there is a certain amount of light produced which would spoil the film. It is possible that this light could be shielded from the film and the ionized air circulated to strategic points to discharge the film without a spark. Also a source of high alternating voltage is necessary. This does not, however, offer any great difficulty as a small induction coil would be sufficient. It is understood that the Fairchild Aerial Corporation is considering tests with equipment of this sort.

7. *Maintenance of Ground Pressure in the Camera and Humidifying the Magazine*

The fact that static does not seem to be present in cameras used on ground levels leads to the consideration of the maintenance of ground conditions in the camera during operations. This would involve heating and sealing so that the pressure, temperature and humidity would remain fixed. To keep the pressure at that existing at ground level is the most difficult, and in view of the results obtained in the experiments discussed in Part II of this paper it may not be necessary. If the camera is humidified or heated or both, the old problem of lens fogging arises. A method of overcoming this by heating the lens and using the light filter as a sort of double window with the space between supplied with a drying agent would no doubt be developed. The question of humidifying is doubtful in view of the results obtained when felt and brass are rubbed on a piece of film and the charging measured. The

charge appeared to be greater at relative humidities around 50 or 60% than in a dry atmosphere. However as has been discussed previously, if high humidities were used, the increased surface conductivity might prevent the accumulation of sufficient charges to damage the film.

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AN INVESTIGATION OF THE DENSITY OF A VAPOR IN EQUILIBRIUM WITH A LIQUID NEAR THE CRITICAL TEMPERATURE[1]

By J. S. Tapp[2], E. W. R. Steacie[3] and O. Maass[4]

Abstract

An account is given of the outstanding work done and theories developed in connection with the critical phenomena during the last century. It was because of certain observations made in this laboratory a short time ago upon reaction rates at the critical temperature that the present investigation was begun with a view to providing more definite data concerning the density of both the liquid and gas in the region of the critical point.

Experimental conditions have been kept under the most rigid supervision and previous errors eliminated or evaluated. A distinctly new technique has been developed, utilizing quartz spirals, for determining the density of both the liquid and gaseous phase almost simultaneously, up to, and past, the point where the meniscus vanishes. The results have been compiled from a great many observations taken over a period of two years upon eight separate units. In general, good agreement has been obtained in all but one case, and a probable solution has been advanced for the exception. Primarily, the paper is an experimental one designed to fill an important gap in previously recorded data.

Extensive theoretical deductions have been purposely omitted because of the radical nature of the findings; and it would be necessary to proceed further with the work before anything really definite might be concluded. Briefly, it might be stated that the results cast considerable doubt upon Van der Waals' classical theory of the continuity of state.

Introduction

The work of Sutherland and Maass (18) in this laboratory upon reaction rates under critical conditions provided evidence of the discontinuity of state. With a view to investigating this condition from another angle, a series of observations and measurements has been undertaken to determine if this discontinuity manifests itself in a number of different physical aspects. The work described here deals with density measurements upon the liquid and gaseous states by a direct method which has several points of superiority over any previous attempts.

The phenomena accompanying the critical temperature have been under observation at one time and another for the last century. Numerous explanations have been offered to account for the observed phenomena, and many determinations upon the existing densities have been tried. A cursory account of the results and their methods of determination will serve to show to what stage the work had progressed when the present investigation was begun.

Almost immediately after Caignard de La Tour (9, 10, 11) had first observed the disappearance of the meniscus at the critical temperature, two explanations for the phenomenon were advanced. (i) The surface tension of a liquid decreases with rise of temperature and if this diminution continued it would be possible to arrive finally at a temperature at which the surface tension

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had fallen to zero. There would be no capillarity and no surface of demarcation existent; in other words the liquid and gas would be visibly indistinguishable and mutually miscible in all proportions. Whether this means that they are physically identical or not, does not follow directly. (ii) As the temperature rises, the vapor density increases and the liquid density decreases; thus it is conceivable for the two to have finally the same density. Ramsay (14, 15) and later Jamin (7, 8) postulated this latter theory to account for the critical phenomenon.

Cailletet and Colardeau (2, 3) seemed to believe that the liquid and gaseous states persisted separately after the critical point had been exceeded. To substantiate this theory, Cailletet and Hautfeuille (4) experimented with iodine and carbon dioxide in a tube. Above the critical temperature, that portion of the tube previously occupied by the liquid retained its violet color while the upper part of the tube remained colorless. This provided fairly substantial qualitative proof of the hypothesis.

The density determinations made by Cailletet and later by S. Young (24) were performed in such a manner as to require observations upon the position of the meniscus. Of necessity the readings had to be discontinued a short distance below the critical temperature. A similar objection may be raised in connection with all the density values obtained in this manner. In spite of this fact, all the investigators extrapolated the results to the critical temperature in the form of a smoothly curving parabola. The general shape of these curves has been similar in all cases, but the exact nature of this parabola in the region of its apex has in no instance been determined experimentally. Its shape has been inferred but never proved. Admittedly, measurements have been made very close to this region, but very close seems hardly good enough when it is considered that densities are known to have been changing at the rate of 4 or 5% per 0.1° C. This shortcoming has been realized to be of considerable significance and a serious handicap in the physical explanation of the phenomena.

The work of Galitzine (5) followed much the same procedure and yielded the same general results as the preliminary work carried on by the writers. Galitzine found that when using ethyl ether, the temperature at which the meniscus disappeared, T_c, was not the same as the temperature at which it reappeared T'_c, and that $T_c - T'_c$ had a positive and constant value, uninfluenced by the relative mass of the material under observation. Furthermore the position in the tube which the meniscus took up for any temperature below the critical temperature was governed by whether that temperature was approached from above or below. Galitzine seemed convinced from the observations that the density in the upper part of the tube containing the ether was considerably less than the density in the lower part, for even 6 or 7° C. after complete homogeneity was apparent to the eye. He stated that this density difference was about 20% and that it maintained itself indefinitely. Small traces of impurities, notably air, were thought to be responsible, but experimental tubes with definitely greater quantities of air included showed no difference from the results obtained in the tubes carefully filled to exclude air.

Several years later, Traube (21) and Teichner (20) attacked the same problem in a slightly different way than had any of the previous workers. Since all the earlier density determinations depended for their evaluation upon the position of the meniscus, and since the meniscus became indistinct and disappeared just at the stage where the measurements were of the greatest significance, it was logical to determine the density in some other manner. The simplest and most direct method possible was employed. Small glass floats, 1 to 2 mm. in diameter of known density were enclosed within the experimental tube along with the material under observation. The effective density of each float was determined, and each float was individually distinguishable, so that at a glance it could be identified with its correct density value. Traube enclosed eight of these small glass floats in each tube; the heaviest had a density of 0.678 and the lightest, about 0.422; the intermediate ones varied from one another by about 0.035. The liquid-vapor system under investigation was carbon tetrachloride.

Teichner increased the number of floats to 15, thereby decreasing the gap between floats by one-half. Both Teichner and Traube took precautions to ensure a steady temperature capable of precise adjustment, but whether they were successful in obtaining a constant and equal temperature throughout the length of the bomb (16 to 20 cm.) has not been recorded, nor did they seem to have any device to detect such an equality had it been present. Both found a density difference of considerable magnitude between the upper and lower parts of the tube after the critical temperature had been exceeded.

The obvious difficulty in connection with the previous method was the gaps between the density values for each of the floats. The number of floats could not have been increased to any greater extent because of the limited space and the difficulty of identification.

F. B. Young (23) after a consideration of the results of previous workers decided that the marked differences in density were to be attributed to the presence of a small percentage of impurity in the substance assumed to be pure. This would serve to reopen the controversy between Traube's liquidogenic and Andrew's classical theories, and to make additional experimental data relating to the critical phenomena of pure substances highly desirable. Young's procedure for filling the experimental tubes with pure substance was exceedingly precise and has been treated at great length in his account of the work. The actual density figures at the critical temperature were obtained in practically the same manner as was employed by Cailletet and were subject to the same criticisms. Young also used a number of close parallel lines set up behind the tube and observed them through the contents of the tube. When the lines showed no discontinuity throughout their length it was assumed that the density along the entire length of the tube was uniform. Furthermore the behavior and distribution of the opalescence were construed to prove certain facts about the distribution of the densities. Gaseous impurities were credited with retarding rather than assisting the formation of opalescence and the rapidity with which the opalescence spread

throughout the tube was hence a measure of the purity. Young believed that with the disappearance of the fog there vanished simultaneously all density differences and since impurities delayed the spread of the fog as well as shortened its duration, he concluded that gaseous residuals were entirely responsible for the differences in density reported by previous workers. It might be well to note that Young considered density equilibrium to have become established throughout the tube during the lapse of a few minutes (he mentions 10 min. in one place) following an alteration in temperature. He ascribed even this lag to the time required for thermal conduction through the walls of the containing vessel.

P. Hein (6) conducted his investigation of the subject in an analogous manner to Traube and Teichner. His results were not in exact accord with theirs. He employed a thermocouple in the heating bath but he did not state how accurate it was nor to what extent it was used. In general, he found that the density differences might be attributed to gaseous impurities but that rapid stirring, performed magnetically within the bomb, offset the effect of the impurities and removed the density difference. In other words he implied that the gaseous impurities only retarded equilibrium and because of this retardation a density difference had been obtained. This conclusion would be valid only if no temperature gradient had existed throughout the length of the bomb, a point which he does not make clear.

Schröer (16, 17) obtained a density-temperature curve with its apex decidedly flattened, but it is to be feared that his pressure manipulation was entirely to blame for this result. Many other investigators have explored this region but have contributed very little reliable information subject to experimental verification.

Even a hasty examination of this short review is sufficient to show that the results, obtained over a considerable number of years, have been at variance amongst themselves. In general, two main divisions seem to have developed; (i) those who have clung to Andrew's classical theory and endeavored to explain the phenomena by reference to his pressure-volume isothermals, and (ii) those who have believed, like Traube, that an intermediate formation of liquidons and gasons must be necessary.

There have been a number of entirely independent investigations involving critical temperature-pressure regions which point to a discontinuity of state at the critical temperature. It has been observed that the solubility of a substance decreases markedly as the critical pressure is approached and reaches a zero value in its neighborhood, which cannot be accounted for by a change in concentration of the solvent (1). Kamerlingh Onnes (13) has determined the dielectric constant of a system through the critical temperature-pressure region. A discontinuity which he has not interpreted seems to be obvious from his data.

The above references are given as evidence that in spite of the apparent continuity of the pressure-volume isothermals a definite discontinuity must exist at the critical temperature. The solubility, velocity of reaction and

dielectric discontinuities might be explained by a regional orientation which may exist in the liquid state, the disappearance of which may greatly influence the so called critical temperature. The suddeness of the disappearance of such a regional orientation with slight temperature changes has already been proved by a dissertation of Nernst's (12).

Apart from this, the existence of a liquid and vapor density difference persisting beyond the critical temperature becomes more or less obvious from the observation that the critical temperature (disappearance of the meniscus) can be observed in tubes containing various amounts of material under observation. On the basis of Van der Waals' theory of the continuity of state, the following calculation will show that the critical phenomenon would be observable only when the tube was filled with the material under inspection to an extent which will conform to a *single* definite critical density value.

Suppose W = weight of material; V = volume of tube; V_g = volume of gas, and d_g = density of gas; V_l = volume of liquid, and d_l = density of liquid; d_c = density of contents at the critical temperature.

Under all conditions:

$$(V - V_g)d_l + V_g d_g = W,$$

Hence $V_g = \dfrac{W - Vd_l}{d_g - d_l}$.

As T approaches T_c, then d_c approaches $\dfrac{d_g + d_l}{2}$

And $W \doteq d_c V$.

Substituting these special conditions in the general equation,

$$V_g = \frac{d_g V - d_l V}{d_g - d_l}$$

$$= \frac{\left[\left(\frac{d_g - d_l}{2}\right) V\right] - Vd_l}{d_g - d_l}$$

$$= \frac{V}{2}\left[\frac{d_g - d_l}{d_g - d_l}\right]$$

Hence $V_g = \dfrac{V}{2}$.

It is seen that the writers are inclined to question the continuity of state in the absolute sense in which Van der Waals advanced it. The discrepancies indicated by the solubility and velocity of reaction experiments cannot be controverted. The discrepancy existing between liquid and vapor densities, implied by the above calculation, and indicated by the experiments of Traube and Teichner, cannot be made to conform to the continuity theory except on the basis of experimental influences involving a vertical temperature gradient, the presence of an impurity, or a pressure gradient based on gravitational attraction. From the point of view of the inflection in the pressure-volume isotherms which gives $dP/dV = O$, it is admitted that the slightest

variation in experimental conditions would tend to bring about an observed variation in density. One of the objects of the work described herein was to eliminate such variations as might be caused by a temperature gradient, or contamination by an impurity; at least to evaluate their influence where a complete removal was prevented by experimental exigencies. The first step in this direction was the adoption of a technique for determining the absolute densities in both the liquid and vapor phase independently under conditions where true equilibrium existed.

Preliminary Experimental Work

The methyl ether was enclosed in a U-shaped tube at first, and was observed at the critical temperature with the arms of the U uppermost, then the tube was inverted and the methyl ether observed again. Observations were then made on a fresh sample of ether enclosed in a straight tube. The usual phenomena were noted, but by making cathetometer readings of the position of the meniscus at various temperatures while approaching the critical temperature and again while receding from the critical temperature, a peculiar fact was brought out. The height of the meniscus above the bottom of the bomb in the first instance was not the same as the height from the bottom in the second case, both at the same temperature. More peculiar still, the difference in the two readings was constant for five observations taken within 2° C. of the critical temperature. It might be well to note here that the bombs were about 30 cm. in length and had an internal diameter of 1.4 cm. It was hoped that this container would reduce the equilibrium lag to a minimum.

Following this last observation, a new bomb was constructed of approximately the same dimensions but having included in it a glass float about 3 cm. long and 0.5 cm. in diameter. The density of the float was made as close to that of the ether at the critical temperature as was possible. The obvious difficulty was the terrific pressure which such a float had to withstand. Many attempts were made before one was obtained, and the successful one had a few drops of the liquid ether included within the float to partly compensate for the external pressure to which it was subjected. Even then it sank through the liquid at a temperature about 4° C. below the critical. A little consideration will show the impossibility of constructing such a float with an effective density equal to, or less than, the density of the vapor at the critical temperature.

The only useful information derived from the preceding experiments was the fact that the bomb tubing employed could successfully withstand the pressures and that the float might be useful if some modifications were introduced. It was at this point that the idea was conceived of continuing the measurements with the floats, but suspending them from a quartz spiral whose extension would give a means of calculating the fraction of the weight of the float not being held up by the buoyant effect of the surrounding medium. It was also thought necessary to have some means of moving the device to various parts of the interior of the bomb. The technical difficulties involved

in such a scheme seemed at first to preclude its realization. The space available was limited by the structural strength of the glass bomb since its internal diameter could not be increased and still continue to give any margin of safety against explosion. Furthermore the moving device had to be compact and such that it would not interfere with the free movement of the float when readings were to be taken and yet allow of complete control from the outside.

Description of Apparatus

The quartz spirals employed were prepared by a machine designed and constructed in this laboratory (19). The spirals had a sensitivity comparable in every respect to that of an analytical balance and yet occupied a space not in excess of 4 cm. in length and 0.5 cm. in diameter.

The bomb (Fig. 1, *A*) was constructed from a section of thick-walled Pyrex tubing 18 in. long, closed at one end. A slight depression was made in the wall at a point 14 in. from the closed end (just below *B*). A piece of thin-walled Pyrex tubing was then selected which just fitted snugly within the bomb tubing but which came to rest against the constriction at *B*. A piece of this tubing $\frac{3}{8}$ in. in length, was fitted with a glass pulley, made from capillary tubing, which revolved freely upon a glass shaft fastened at both ends to the upper edge of the ring. Upon the lower edge of the ring were two glass guides, one at the centre and the other at the edge.

A thin wire nail was fitted loosely into a Pyrex sheath with very thin walls, and the sheath allowed to extend a short distance past both ends of the nail (*E*). This particular design prevented the nail from sloping away from the interior wall of the bomb at the end opposite to which the magnet was applied. A small glass hook on one end completed this unit.

The counterweight (*W*) was a piece of capillary tubing adjusted in size so that its weight was almost equal to that of (*E*). A closed hook at the top and an open hook at the bottom completed this part.

The float (*D*) was of Pyrex glass; its shape was uniform and of such a design as to best resist high pressures without collapsing. The volume was made as near to 1 cc. as possible and its weight kept between 0.4 and 0.5 gm. A neat open hook was sealed to the top of it. The accurate determination of the volume of the float presented considerable difficulty. A small specific gravity bottle was constructed with a wide mouth closed by a ground glass stopper and a capillary overflow from the opposite end. The float itself was weighed

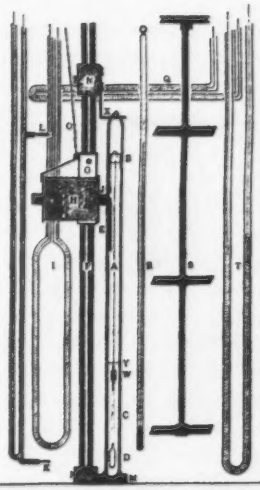

FIG. 1. *Diagram of apparatus for heating the experimental tubes through the critical temperature, showing the construction of the moving spiral and float device and the general lay-out of the various parts.*

and the weight corrected for the buoyant effect of the atmosphere. The specific gravity bottle was weighed full of distilled water at a known temperature, and again full of water with the float included within it. In this way a consistent determination of the volume of the float could be obtained.

A fine silk thread was tied to the glass-sheathed nail (*E*), then threaded up through the outside guide on (*B*), thence over the pulley and down through the centre guide to the counterweight (*W*). The length of the thread was such that with the nail about 1 in. from the bottom of the bomb, the counterweight (*W*) was against the saddle (*B*). The open hook of the float (*D*) was slipped into the ring at the bottom of the calibrated spiral (*C*) and the hook carefully closed using a small flame. Similarly the hook on the bottom of the counterweight (*W*) was connected to the top ring of the spiral. The whole suspension was lowered into the bomb.

The bomb was clamped in an upright position and immersed in water up to the level of (*B*). At a point 2 in. above (*B*) a uniform constriction was made in the tube, leaving only a narrow aperture. This was done because the silk thread had to be kept cool while it was only about 1 in. removed from molten Pyrex. Furthermore it was desired to leave as little "dead-space" as possible above the saddle. A short piece of Pyrex tubing was then sealed on to the open end of the bomb and connected to the filling device. (See Fig 2, *T*.)

The Methyl Ether Preparation and Purification Train

With reference to Fig. 2, the apparatus may be divided roughly into three sections, the divisions being based upon the use of each section.

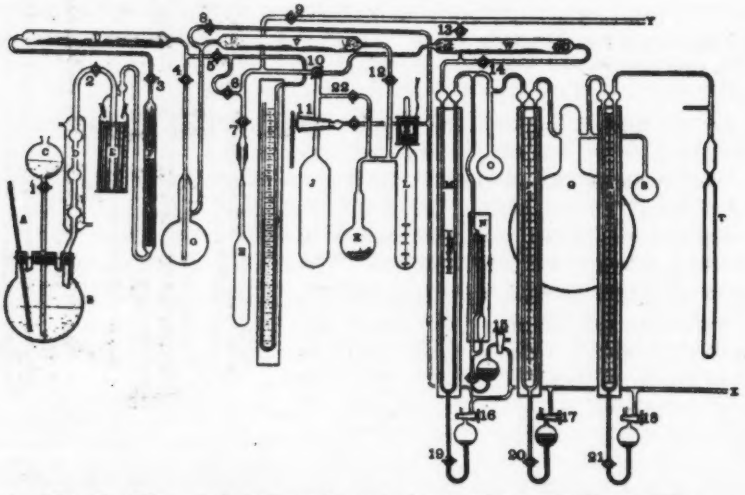

FIG. 2. *Diagram of apparatus for preparing, purifying and delivering pure methyl ether to the experimental tubes.*

(i) (Beginning at the left.) From (*A*) to (*G*) was designed for the preparation and crude purification of the ether.

(ii) From (*H*) to (*L*) was used for the further refinement and delivery to storage bombs, as well as for introducing the ether back into the system from storage when desired.

(iii) The section (*M*) to (*S*) served to admit measurable quantities of pure ether to the finished bomb without the danger of contamination with air or stopcock grease.

(*B*) was a one-litre Pyrex flask fitted with a 0° to 360° C. thermometer (*A*), a dropping funnel (*C*) and a water-cooled condenser (*D*). (*E*) was a bubbler packed with glass rods and filled with concentrated sulphuric acid. Tubes (*F*) and (*U*) were supplied with calcium chloride lumps and phosphorus pentoxide, respectively. (*G*) was a 300-cc. Pyrex flask.

In operation, 500 cc. of concentrated sulphuric acid was added to (*B*), stopcocks Nos. 2, 3 and 4 were opened and a refrigerant (−80° C.) was placed around (*G*). Stopcock No. 5 was turned so as to connect the system to the mercury manometer (*I*). A bunsen burner was placed under (*B*) and stopcock No. 8, which communicated with the water vacuum line, was manipulated so as to maintain a negative pressure of about 4 cm. of mercury as registered on (*I*). When the thermometer (*A*) reached 130° C., the methyl alcohol in (*C*) was admitted drop by drop to (*B*) through the glass valve No. 1. The temperature was kept steady and the pressure maintained as described. Liquid methyl ether collected in (*G*).

Stopcocks Nos. 2, 3 and 4 were closed and No. 12 opened, the refrigerant was transferred from around (*G*) to (*L*) and the methyl ether slowly distilled from (*G*) to (*L*) passing through the phosphorus pentoxide drying tube (*V*). The container (*L*) had about one-half the capacity of (*G*) and was fitted with an electromagnetically operated glass stirrer. When (*L*) was three-quarters full, stopcock No. 12 was closed, the refrigerant was replaced about (*G*) and also around (*K*). An empty Dewar flask was set around (*L*) and the stirrer started. The ether very slowly distilled, without bumping, into (*K*). The flask (*K*) contained about 4 gm. of sodium wire, which it was hoped would take out the last traces of water and alcohol. The last portion (15 cc.) in (*L*) was allowed to escape each time. From (*K*) the ether was distilled into (*J*). The remainder of the ether which had been left in (*G*) was put through (*L*) and (*K*) as previously described and finally added to that already in (*J*).

The storage bomb (*H*) was made of ordinary glass tubing and could have any desired capacity from 10 to 50 cc. It was fitted inside the glass tubing just below No. 7, and the joint made air-tight by a section of rubber tubing wired in place. Stopcocks Nos. 6 and 7 were opened and No. 11 was closed; No. 10, a two-way valve, was turned so as to connect (*J*) with (*H*). Vacuum was applied by opening No. 9, which communicated with (*Y*) the high vacuum line. When (*I*) registered a good vacuum, No. 9 was closed and the contents of (*J*) allowed to warm up to about 0° C. This served to create a pressure of about two atmospheres in (*H*). A momentary opening of No. 11 returned

the pressure in (*H*) to atmospheric, which was again reduced, as before, to a vacuum. After about three repetitions of alternate vacuum and pressure, the refrigerant was placed around (*H*) and stopcock No. 11 carefully adjusted so as to maintain a pressure of about one atmosphere as read on the manometer (*I*). Ether (50 cc.) could be transferred in this way from (*J*) to (*H*) in about 4 min.

When (*H*) was *four-fifths full* of liquid, valve No. 11 was closed and the stopcock No. 9 opened, the cooling mixture was left around (*H*) and a flame applied to the constriction in the neck of the bomb. When the constriction collapsed the bomb was removed and could be kept until needed at room temperature. Other bombs were placed in position and filled as before until the supply in (*J*) became exhausted.

The section of the apparatus on the right of the diagram consisted essentially of three mercury seals (*M*), (*P*) and (*R*). On (*P*) and (*R*) were carefully calibrated scales extending their full length, while (*M*) had only a short section of rough scale at its central point. Each branch of the U in every seal was topped by a 50-cc. bulb in order to prevent mercury from being forced through the system when one or other of the seals was pulled out while a difference of pressure existed on opposite sides of it. Even with this precaution, under pressure differences of more than 10 cm. of mercury, the seal could not be successfully withdrawn. Stopcocks Nos. 16, 17 and 18 were of the two-way variety, one lead communicated with the water vacuum line (*X*), while the other opened to the atmosphere. Stopcocks Nos. 19, 20 and 21 were ordinary one-way valves which were necessary to arrest the upward or downward motion of the mercury at the will of the operator. The length of the arms of each mercury seal was roughly 120 cm.; the height from the mercury level in the reservoir to a point half way up the U was 76 cm. The mercury was carefully cleaned and dried and its level was never allowed to fall below any one of stopcocks Nos. 19, 20 and 21.

(*N*) was a McLeod gauge capable of measuring pressures down to 0.0002 mm. of mercury. (*O*) was a 50-cc. Pyrex flask, (*Q*) was a Pyrex round-bottom flask of roughly six-litre capacity. It was planned at first to use this calibrated volume for introducing accurate quantities of gaseous methyl ether to the bomb, but in practice it was never used as such. The small bulb (*S*) was introduced to enable the gaseous methyl ether which had been accumulated in (*Q*) to be condensed, thus allowing the mercury seal (*R*) to be pulled out without forcing mercury out of (*R*) into (*T*).

All the mercury seals were drawn out, stopcock No. 14 was closed and No. 13 opened thereby connecting the system from (*M*) to (*T*) with a Langmuir mercury pump backed up by a mechanical high vacuum pump. The evacuation was allowed to continue for a period of 4 or 5 hr., at the end of that time the pressure had been reduced to about 0.0003 mm. of mercury. The seal (*M*) was raised to the position shown in the diagram and the extent of the vacuum was tested occasionally over a period of 2 hr. to detect, if possible, any leaks. Very little trouble was encountered in making the

system air-tight, and on several occasions the pressure did not appreciably alter even when left for 24 hr.

When testing the system for leaks one of the methyl ether storage bombs of 35 or 40 cc. capacity was placed in a refrigerant (−20° C.) for 5 min., then removed, wrapped in a towel, and the tip broken off. The open end was then inserted below stopcock No. 7 and held there in the manner described previously. The contents was allowed to distil over into (*J*) and held in readiness. The phosphorus pentoxide drying tube (*W*) was replaced by a fresh one every time a new bomb was to be filled. When the system to the right of (*M*) had been found capable of maintaining a vacuum, stopcock No. 10 was turned so as to connect (*J*) with (*W*), stopcocks Nos. 13 and 14 were opened and the small volume from No. 11 over to (*M*) was evacuated thoroughly. Stopcock No. 13 was then closed and No. 11 opened until the pressure as indicated on (*M*) was about one atmosphere. The evacuation was then repeated, followed by the building up of the pressure as described. This process was performed about six times to be sure that whatever pressure did remain was due to methyl ether and not to air.

Mercury seals (*P*) and (*R*) were raised to their midpoint and (*M*) was drawn down, a refrigerant (−80° C.) was placed around (*O*). When about 25 cc. of liquid had collected in (*O*), the distillation was stopped and about 5 cc. allowed to evaporate out of (*O*) into the pump system (*Y*). The seal (*M*) was immediately returned to its position as shown in the diagram. All the precautions described were taken to preclude the possibility of introducing air into the carefully evacuated system.

The mercury seal (*P*) was drawn out, the refrigerant around (*O*) was removed, and the pressure in (*Q*) was allowed to build up to about 80 cm. of mercury, as registered on (*R*). The mercury in (*P*) was then forced up into position by pressure applied to the atmosphere lead of stopcock No. 17. Simultaneously the refrigerant was returned to (*O*). Another Dewar flask containing refrigerant (−80° C.) was placed around (*S*) to reduce the pressure in (*Q*) to such a value that the seal (*R*) could be withdrawn. The refrigerant was then placed around (*T*) and the seal (*R*) immediately drawn down. When the desired amount of ether had been condensed in (*T*) the seal (*R*) was again raised. By means of the oxy-gas flame, the bomb (*T*) was sealed off at the constriction and removed from the system. Incidentally, it was discovered that a bomb filled with liquid at −80° C. to *twenty-four eighty-fifths* of its total volume gave an experimental tube in which the meniscus disappeared at the critical temperature at a position practically the same as it occupied at room temperature. This generalization has been tried for methyl ether and for ethylene and found to be true in both cases.

The Heating Bath

The accompanying diagram (Fig. 1) represents the arrangement of the heating apparatus with the bomb in position. The actual container (not shown in diagram) was a Pyrex jar, 18 in. high and 8 in. in diameter. The jar contained 3 gal. of glycoline which served as the heating medium. A certain

amount of detail has been omitted from the drawing so as not to confuse with the really essential features; furthermore some of the parts have been slightly misplaced in order that all may be shown more clearly.

The thick-walled Pyrex glass bomb (*A*) contained the methyl ether with the meniscus level at (*Y*). It was securely set in a pocket in the wooden base (*M*) and held at the top by the heavy copper strip (*X*) which had a hole drilled in it large enough to fit over the tip and rest firmly on the shoulder of the bomb. This copper strip was in turn bolted to the collar (*N*) which was set-screwed to the heavy brass rod (*F*). This particular arrangement allowed for the easy removal of the bomb and yet assured that when in position it would be held rigidly in place. Great care was taken to be sure that the bomb was absolutely vertical and that nothing altered this in the process of heating.

The brass shaft (*F*), $\frac{3}{4}$ in. in diameter, had a key-seat cut along its entire length; the brass collar (*G*) was fitted with a key which allowed the free vertical movement of (*G*) but restricted its rotation upon the shaft to almost zero. Attached to the collar (*G*) was an electromagnet (*H*) wound upon a hollow brass spool with brass ends. Through the brass spool was inserted a solid wrought iron core (*J*) which fitted closely but yet had free longitudinal movement within the spool. The correct length of the core was such, that with the bomb in position, about three-eighths of an inch more of the core projected from the spool at the end remote from the bomb than from the end next to the bomb. The purpose of this was to ensure that the pole piece was kept in direct contact with the exterior of the bomb throughout the latter's entire length by means of the natural spring created by the core endeavoring to centre itself in the electromagnetic field. This may seem like a superfluous refinement, but until its adoption all sorts of difficulties were encountered in getting a firm grip upon the nail.

The chain (*O*) was fastened to (*G*) and proceeded upward and over a suitable sprocket mounted upon a shaft, and thence to a counterweight outside the bath. The shaft had a pulley over which ran a belt that extended back to another pulley and crank situated beside the operator. By turning the crank one way or the other, the magnet device could be raised or lowered at the will of the experimenter, and when the electromagnet was turned on, the nail within the bomb followed along, thereby placing the float (*D*) at any desired position between the upper and lower extremities of its movement.

The heaters (*I*) and (*T*) were connected in parallel with each other and in series with a suitable rheostat which could be adjusted to vary the current from one to nine amperes. Since the temperature control was entirely manual, a switch was connected *across* the rheostat leads, and when the temperature was observed to be falling slightly, this switch was closed for four or five seconds, thus raising the current flowing through (*I*) and (*T*) to a maximum for that length of time. When the switch was reopened the original flow of current was resumed. This dispensed with the difficulty of resetting the rheostat at the correct position after each restoration of temperature. With

a little practice, the temperature control became a comparatively easy matter and needed to be checked not oftener than once every 5 or 10 min. This amount of attention served to maintain the temperature to within one-twentieth of a degree of the desired value at all times.

The heater (*Q*) was on a separate switch and had its own controlling rheostat. (*L*) and (*K*) were the upper and lower junctions of an alumel-chromel thermocouple. Actually (*L*) and (*K*) were exactly duplicated by a second set of similar junctions connected in series with those shown, the purpose being to give greater sensitivity. The carefully insulated leads from the thermocouple were connected to a lamp and scale galvanometer. This device readily detected differences in temperature between the upper and lower junctions of the order of 0.01° C. Using this as a detector, the current necessary to maintain any desired temperature was correctly proportioned between (*Q*) and the double unit (*I*) and (*T*) so that the galvanometer registered no deviation. Taking no precautions, *i.e.*, without operating (*Q*), the top of the bath would become from one- to two-tenths of a degree cooler than the bottom. The position of the junction (*K*) was not as close to the heater (*I*) as the drawing would indicate. Actually, both (*K*) and (*L*) were situated very close to the top and bottom of the bomb respectively, while heaters (*I*) and (*T*) were removed as far as possible from each other and from the bomb. A fourth heater (not shown) was also in the bath, but was used only in conjunction with (*I*) and (*T*) to raise the temperature fairly rapidly in the early stages of the heating, but was never used to maintain a temperature.

The thermometer (*R*) had a temperature range of 0 to 200° C., graduated in fifths, and was calibrated against a standard thermometer over the range of 100 to 150° C. The stirrer (*S*) occupied a central position in the bath, was of a sturdy construction involving double bearings top and bottom, and was driven by a belt from a variable speed motor. The stirrer blades were about 3 in. long from tip to tip and were rotated at a brisk rate of speed to eliminate as far as possible any stagnant oil. Directly behind the bomb, but outside the glass containing vessel was a vertical row of four 100-watt frosted Mazda bulbs which provided a good clear illumination throughout the length of the bomb.

The whole bath was thermally insulated with asbestos and rested upon a 50-lb. slab of slate. The entire unit was housed within a sheet-steel tank, 2½ ft. high, 2 ft. wide and 1½ ft. from front to back. The front face of the tank was inset with a plate-glass window, 23 in. high and 7 in. wide. Outside of this window were two wooden wings, securely fastened in such a manner as to leave only a sufficiently wide slit to make the bomb and thermometer visible. Ten feet back from this was a tough fibre-board screen, 7 ft. high and 7 ft. across, firmly fastened in an upright position. A plate glass window 2 ft. long and 6 in. wide was set in this screen at approximately the same level as the window in the tank. Behind the screen were all the electrical controls; the cathetometer, for measuring the spiral extension; the telescope for observing the thermometer; and the operator. Both the cathetometer

and the telescope were especially constructed to give a high magnification at the distance for which they were used.

The apparatus as herein described has given good satisfaction for about 500 hr. of actual operation. The factor of reliability was of great importance because the operator could not safely approach the heater to carry out any adjustments, alterations or repairs while the temperature was up.

Experimental Procedure

In the main, three types of determinations were attempted on each bomb.

(i) The density was measured from the upper to the lower limit of movement of the suspension while the bomb was maintained at some definite temperature.

(ii) The density above and below the position at which the meniscus disappeared was determined at a succession of different temperatures; these temperatures first being approached from below and then from above.

(iii) The effect of a vertical temperature gradient was thoroughly investigated. The importance of removing this gradient will be shown in some detail in the following results.

Since all the weight measurements depended upon the length of the spiral which was measured by optical means, it was necessary to check up on any possible optical distortion brought about by the various layers of glass and oil between the spiral and the eye. No correction was found to be necessary.

In all the bombs, the following data had to be compiled before the parts were assembled:

(i) The volume of the glass float (V); (ii) the weight of the float (W); (iii) the sensitivity of the spiral (S); (iv) the normal length of the spiral (N).

With regard to the value of (V), it might possibly be thought that under the influence of the pressure encountered under working conditions a slight contraction might be caused, however, up to pressures of 55 atm. no such contraction was measurable; at least if it did exist it was less than the experimental error (22).

With the foregoing information it was possible to determine the density of the medium surrounding the float at any time. The length of the spiral from tip to tip was measured by the cathetometer, say (X) mm. From this was subtracted the normal length, (N), and the result multiplied by the sensitivity of the spiral (S). The product was subtracted from the weight of the float (W), and divided by the volume of the float (V), the result of this division gave the density. In abbreviated form it may be expressed as:

$$d = \frac{W - (X - N)S}{V}$$

The cathetometer readings could be checked repeatedly to 0.05 mm., but since two readings had to be made for each density determination, the extreme limit of error might be considered as 0.10 mm. An alteration of this extent in the cathetometer reading would change the density value in a typical case by 0.0005.

Experimental Results

The following tables have been selected from some 500 pages of data with no regard for chronological sequence. A total of seven different bombs containing varying quantities of liquid have been investigated successfully over a period of some 500 hr. of observation. Obviously, only sufficient figures can be given to indicate the trend of the results.

TABLE I

RESULTS OBTAINED WITH BOMB NO. 9

I			II			III		IV	
Temp., °C.	Density (a)	Density (b)	Temp., °C.	Density (a)	Density (b)	Temp., °C.	Density (a)	Temp., °C.	Density (a)
126.3	.2128	.2122	128.9	.2662	.2635	125.9	.3406	128.9	.2722
126.5	.2170		127.3	.2634		126.3	.3332	126.9	.2722
126.7	.2202	.2192	126.9	.2613	.2620	126.7	.3207	126.5	.3020
126.9	.2255		126.7	.2606		127.1	.3138	126.3	.3168
127.1	.2296	.2296	126.3	.2384	.2345	127.9	.2967	126.1	.3288
127.3	.2338		125.9	.2220	.2190	128.9	.2854	125.9	.3367
127.9	.2432	.2449	124.9	.2008	.1977	131.1	.2772		
128.9	.2523	.2535				132.3	.2742		
129.9	.2583					135.1	.2722		
131.1	.2618	.2606							
132.1	.2638	.2624							
135.0	.2662	.2648							

NOTE: *See Fig. 3. I, Float above visible meniscus, temperature approached from below; II, float above visible meniscus, temperature approached from above; III, float well below visible meniscus, temperature approached from below; IV, float well below visible meniscus, temperature approached from above.*

The temperature was equalized throughout the bath. Density (a) and Density (b) represent values obtained on different days.

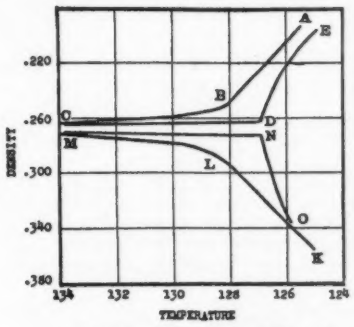

FIG. 3. *Shows the relation between density and temperature and the influence of the direction of approach to any particular temperature. Curve ABC corresponds to section I, curve EDC to section II, curve KLM to section III, and curve ONM to section IV of Table I.*

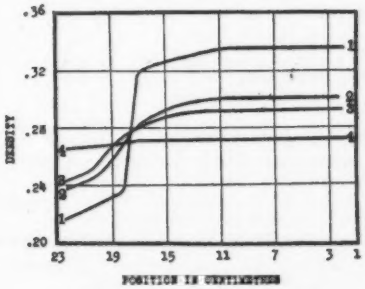

FIG. 4. *Shows the relation between density and position in the bomb for four different temperatures in the region of the critical temperature. Curve No. 1 corresponds to section I, curve No. 2 to section II, curve No. 3 to section III and curve No. 4 to section IV of Table II.*

Table I was compiled from observations on bomb No. 9. The conditions of heating and the position of the density value recorded are noted in connection with each section of the table.

Table I shows the variations in the density values at positions well above and well below the meniscus, while the temperature is raised or lowered through the point where the meniscus vanishes. Table II shows how the densities are distributed throughout the length of the bomb while the temperature is maintained constant. Again, bomb No. 9 is the one chosen to illustrate this point. The meniscus became invisible to the eye at 126.9° C., at a point 18 cm. from the bottom of the bomb.

TABLE II

DISTRIBUTION OF DENSITIES IN BOMB NO. 9 AT VARIOUS TEMPERATURES

I		II		III		IV	
Temp., 127.1° C.		Temp., 126.7° C.		Temp., 125.5° C.		Temp., 135.1° C.	
Position, cm.	Density	Position, cm.	Density	Position, cm.	Density	Position, cm.	Density
22.6	.2421	22.6	.2384	22.1	.2178	23.2	.2657
20.5	.2560	20.2	.2454	21.0	.2253	20.6	.2685
18.4	.2724	18.1	.2713	19.7	.2290	17.0	.2713
16.2	.2847	16.1	.2867	18.6	.2329	15.5	.2713
12.1	.2925	12.5	.2985	16.6	.3201	12.2	.2729
7.6	.2930	9.2	.3009	12.7	.3305	8.8	.2725
2.0	.2934	5.7	.3004	10.9	.3326	5.4	.2720
		2.2	.3006	8.6	.3363	1.6	.2727
				5.7	.3358		
				1.8	.3360		

NOTE: *The numbers appearing under the heading "position" denote the cathetometer reading corresponding to the upper tip of the float. The bottom of the bomb on the same scale is equivalent to a reading of −1.2 cm.*

The temperature was equalized throughout the bath. The contents of the bomb was well stirred. See Fig. 4 for graph.

From a graph similar to that of Fig. 4, but containing lines for two more temperatures, Table III was compiled.

TABLE III

DISTRIBUTION OF DENSITIES IN BOMB NO. 9 AT VARIOUS TEMPERATURES

Temp., °C.	Density at 22 cm.	Density at 2 cm.	Diff.	Temp., °C.	Density at 22 cm.	Density at 2 cm.	Diff.
125.5	.2200	.3360	.1160	128.9	.2580	.2800	.0220
126.7	.2390	.3010	.0620	132.3	.2650	.2730	.0080
127.1	.2450	.2940	.0490	135.1	.2680	.2720	.0040

NOTE: *See Fig. 5 for graph of this table.*

The influence of a temperature gradient along the length of the bomb is shown clearly by a consideration of the following results:

TABLE IV

INFLUENCE OF A TEMPERATURE GRADIENT ALONG THE LENGTH OF THE BOMB

I				II			
Temp., ° C.	Density	Temp., ° C.	Density	Temp., ° C.	Density	Temp., ° C.	Density
118.4	.1440	126.1	.271	124.4	.3580	126.4	.2585
120.9	.1600	126.4	.271	124.8	.3491	126.6	.2596
125.5	.1724	127.0	.271	125.4	.3323	127.0	.2596
124.1	.1926	128.7	.271	125.8	.3161	129.7	.2616
125.9	.2467	130.9	.270	126.0	.2585	130.9	.2629
126.0	.2655	133.3	.270	126.2	.2585		

NOTE: *I, the float was at a position above where the meniscus disappeared; II, the float was at a position below where the meniscus disappeared. In both I and II the bottom of the bomb was slightly warmer than the top* ($\frac{1}{10}$° C.). *See Fig. 6 for graph.*

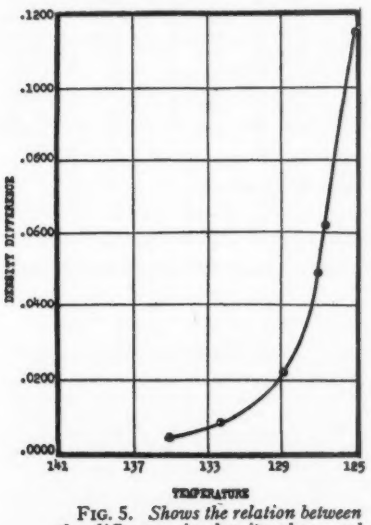

FIG. 5. *Shows the relation between the difference in density above and below the position of meniscus disappearance and the temperature. (Corresponds to Table III.)*

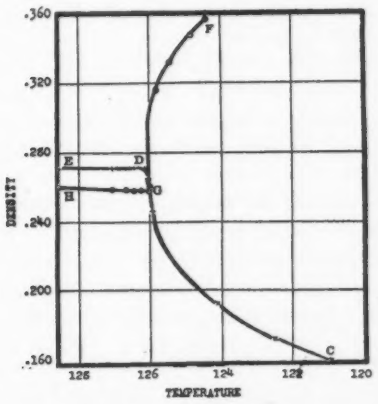

FIG. 6. *Shows the relation between density and temperature in the critical region when the bottom of the bomb is* $\frac{1}{10}$ *C. warmer than the top. Curve FGH corresponds to section I and curve CDE corresponds to section II of Table IV.*

The complete reversal in the existing density conditions brought about by the slight temperature excess at the bottom is so striking that unless confirmation had been supplied by repeated trials on many bombs, the results would not have been thought reliable. So interesting was this phase of the work that much time was spent upon it and no amount of stirring or agitation within the bomb was ever found that could materially alter the above-outlined

state of affairs. Arising out of the previous work came the thought that possibly the oft-repeated differences in density obtained with equalized temperature throughout were caused by an equilibrium lag between the two phases since the conditions could be so easily reversed by the appropriate temperature gradient.

Table IVa shows the result of maintaining a bomb at a temperature slightly above the critical temperature for a prolonged period of time, accompanied by continuous and vigorous stirring within the bomb.

From this table it will be seen that apparently a steady state of affairs has been arrived at and the density above the position of disappearance of the meniscus is still less than below.

TABLE IVa

INFLUENCE OF TEMPERATURE HELD SLIGHTLY ABOVE THE CRITICAL

Time, min.	Position	Density	Time, min.	Position	Density	Time, min.	Position	Density
60	Bottom	.2899	160	Top	.2585	240	Bottom	.2798
90	Bottom	.2865	165	Top	.2590	255	Bottom	.2814
105	Bottom	.2865	180	Top	.2606	260	Bottom	.2814
120	Bottom	.2865	195	Top	.2618	270	Top	.2611
150	Bottom	.2865	210	Top	.2627	280	Top	.2618
153	Top	.2576	225	Top	.2634	290	Bottom	.2805
			235	Top	.2646	305	Top	.2632
						345	Top	.2646

NOTE: *Bomb No. 9. Temperature 127.9° C., temperature equalized.*

To show the result of a *succession* of temperature gradients upon any one bomb at some temperature slightly above the critical temperature, consider the following tabulation:

TABLE V

INFLUENCE OF A SUCCESSION OF TEMPERATURE GRADIENTS AT TEMPERATURE SLIGHTLY ABOVE THE CRITICAL

Series no.	Gradient	Density diff.	Time, min.	Series no.	Gradient	Density diff.	Time, min.
1	(i) Bottom + ½° C.	0	44	4	(i) All equalized	.0281	100
	(ii) All equalized	0	40		(ii) Bottom + 1/10° C.	0	75
2	(i) All equalized	.0275	85		(iii) Top + 1/10° C.	.0139	120
	(ii) Top + 1/10° C.	.0402	45		(iv) All equalized	0	35
	(iii) All equalized	.0257	20	5	(i) Bottom + 1/10° C.	0	140
	(iv) Bottom + 1/10° C.	.0026	55		(ii) All equalized	0	28
3	(i) Bottom + 1/10° C.	0	100		(iii) All equalized	0	26*
	(ii) All equalized	0	75				
	(iii) Top + 1/10° C.	.0184	10				

**While the average temperature was lowered from 127.9° to 126.4° C.*

NOTE: *Bomb No. 9, average temp. of bath 127.9° C. Critical temperature (disappearance of meniscus) 126.9° C.*

To leave no doubt as to the meaning of the data in Table V, one of the series of experiments (Series No. 2) is described at some length.

The temperature was raised from room temperature to a point 1° C. above the critical temperature with a uniform distribution of temperature throughout the bath. (*All equalized.*) After *85 min.* the density difference was *0.0275*. The average temperature of the bath being kept constant, a temperature gradient was maintained so that for *45 min.* the *top* was $\frac{1}{10}$° *C.* higher than the bottom; under these conditions the density difference was increased to *0.0402*. Then upon *equalization* of the temperature, after *20 min.* the density difference returned to about the original value, *0.0257*. When the *bottom* of the bomb was maintained at a $\frac{1}{15}$° *C. warmer* than the top, the density difference after *55 min.* was found to be only *0.0026*.

Keeping a temperature gradient such that the bottom of the bomb is warmer than the top, even by a slight amount, effectively does what any amount of stirring over a much longer period of time at equalized temperature fails to accomplish, namely, the removal of the density difference.

A Note on the Nature of the Fog

Under the conditions imposed in section (iii), Series No. 5, of Table V, the formation and disappearance of the fog presented a remarkable sight. The tube remained perfectly clear down to 126.5° C.; at 126.4° C. a mist flashed into view throughout the entire length of the bomb. The intensity was uniform and the distribution complete. As the temperature dropped, the mist increased in intensity, and at 126.3° C. entirely concealed every trace of the spiral and float. Suddenly a clear spot appeared immediately at the bottom of the bomb. This clear spot swept upward at about 1 cm. per sec. Simultaneously a clear region fell, with equal rapidity, from the top. The clear regions met about 12 cm. from the bottom and revealed a sharp meniscus. The whole dissipation of the fog occupied not more than 15 sec. It will be noted that the temperature of the reappearance of the meniscus was about 0.5° C. *lower* than that of its disappearance.

Table VI shows the way in which the density difference between the upper and lower portions of the bomb varies with respect to temperature in a number of different bombs. In all cases the temperature in the bath had been equalized throughout the length of the bomb, and a period of time sufficiently long had been allowed for apparent equilibrium to have become established. The tem-

TABLE VI

COMPARISON OF DENSITY EFFECTS IN DIFFERENT BOMBS

Temp., ° C.	Density difference		
	Bomb No. 9	Bomb No. 10	Bomb No. 13
0.1	—	—	0
0.2	0.0490	0.0585	0
1.0	.0300	.0187	0
2.0	.0220	.0067	0
5.4	.0080	.0020	0

NOTE: *Height of meniscus above the bottom of the bomb at the moment of disappearance of the meniscus—bomb No. 9, 18 cm.; bomb No. 10, 4 cm.; bomb No. 13, 11.2 cm.*

perature values listed are in terms of degrees Centigrade *above* the temperature at which the meniscus became invisible. The relative amounts of liquid in each bomb may be judged from the height at which the meniscus vanished.

A survey of Table VI shows that the three bombs do not agree on a number of points, the chief one being that No. 13 exhibits no density difference immediately above the critical temperature. This was the only bomb constructed which behaved in this way and a possible explanation lies in the fact that the proportion of liquid to available space in this particular bomb was unique. A diagram (Fig. 7) has been prepared to show just how the three bombs differed with respect to the quantity of liquid used in each case, and also to show how this quantity of liquid rose or fell up to the critical temperature. It must be understood that the rate of heating could modify the particular shape of any one of the curves, but a fair representation has been made under a slow rate of heating. For reference purposes, the curves may be reduced to their respective tangent values.

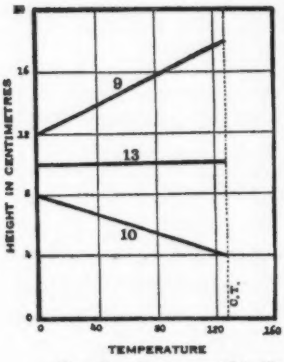

FIG. 7. *Shows graphically the behavior of the meniscus in three different bombs under the influence of heating.*

Curve No. 9 for bomb No. 9, tan = $+\frac{1}{2}$; Curve No. 10 for bomb No. 10, tan = $-\frac{1}{2}$; Curve No. 13 for bomb No. 13, tan = 0.

It may be seen from the preceding paragraph that the three bombs under consideration differed from one another, in construction, in one important factor. In bomb No. 9 the meniscus rose steadily up to its point of disappearance, in bomb No. 10 it fell steadily, and in bomb No. 13 it neither rose nor fell. This last condition is very difficult to duplicate and was not met with in any other bomb constructed throughout this work. Since the same bomb which fulfilled this peculiar condition also exhibited no density difference between the top and bottom above the critical temperature, it might be logical to assume that the diversions were interrelated. The purity of the methyl ether and its manner of addition to the bombs were identical in every case.

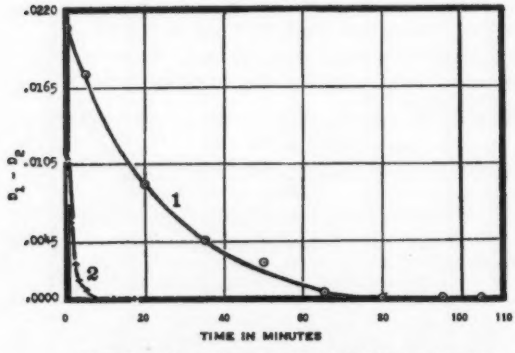

FIG. 8. *Shows the rate with which the density of the vapor approaches its final value (no stirring) at two different temperatures above the critical. D_1 is the density of the gas at infinite time. D_2 is the density of the gas at the end of time T. Curve No. 1 was made at a temperature of 127.1° C., i.e., 0.2° above the critical temperature. Curve No. 2 was made at a temperature of 132.3° C., i.e., 5.4° above the critical temperature.*

The following tables have been compiled with a view to showing

TABLE VII

EFFECT OF NO STIRRING WITHIN THE BOMB ON FINAL DENSITY VALUE

*Time, (t) min.	$D_1 - D_2$	**Time, (t) min.	$D_1 - D_2$
0	0.0215	0	0.0110
5	.0177	1	.0061
20	.0090	2	.0028
35	.0046	3	.0015
50	.0028	5	.0007
65	.0005	7	.0000
80	.0000	12	.0000
95	.0000	17	.0000
105	.0000		

NOTE: *Bomb No. 13. D_2 was the density at time t. D_1 was the density at infinite time, i.e., the highest density value obtained.*

**Temp. 0.2° above the critical. No stirring within the bomb.*

***Temp. 5.4° above the critical. No stirring within the bomb.*

TABLE VIII

EFFECT OF STIRRING WITHIN THE BOMB ON FINAL DENSITY VALUE

*Curve 3, Fig. 9		**Curve 4, Fig. 9	
Time, min.	$D_1 - D_2$	Time, min.	$D_1 - D_2$
0	0.0208	0	0.0136
3	.0147	10	.0091
8	.0091	18	.0064
13	.0077	26	.0050
43	.0042	35	.0035
88	.0031	50	.0031
133	.0013		
163	.0000		
178	.0000		
193	.0000		
208	.0000		

**Temp. 0.2° C. above the critical. No stirring within the bomb. Temperature equalized.*

***Temp. 0.2° C. above the critical. Continuous stirring within the bomb. Temperature equalized. See Fig. 9.*

the manner in which the density in the gaseous phase approaches its final value when uninfluenced by any stirring. Two different temperatures have been selected to exhibit this, one only a short distance above the critical temperature, and the other a considerable distance above. In neither case was a meniscus nor any discontinuity apparent to the eye.

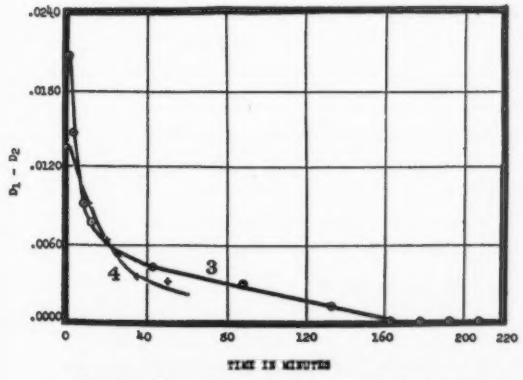

FIG. 9. *Shows the small influence which stirring has upon the rate with which the vapor reaches its final density value. D_1 is the density of the gas at infinite time. D_2 is the density of the gas at the time T. Curve No. 3 was made at a temperature of 127.1° C., i.e., 0.2° above the critical temperature. No stirring was performed within the bomb during the time these results were being obtained. Curve No. 4 was made at a temperature of 127.1° C., i.e., 0.2° above the critical temperature. The contents of the bomb was well stirred during the time these results were being obtained.*

In Table VII the value 0.2538 was taken as the gaseous density at infinite time. This value was arrived at by maintaining the bomb at either of the two temperatures for a prolonged period of time. Furthermore, this was also the density value for the lower portion of the bomb and might well be considered as the mean critical density for this particular tube. See Fig. 8.

Table VIII has been compiled to show the effect of stirring within the bomb upon the rate with which the density value of the gaseous medium

approached its equilibrium value. The data were obtained from bomb No. 10 in which the density of the upper portion of the tube never reached as high a value as that in the lower. The value chosen to represent D_1 was the largest value ever obtained in any run with the temperature equalized. The figures for curve No. 4, Fig. 9, were not obtainable past the point indicated on the graph, but the general trend does not appear to be radically different from that in curve No. 3. This relatively close agreement between the two curves seems to indicate that diffusion alone could not have been the cause for the slow adjustment of the density to its final equilibrium value.

Summary

To illustrate the general nature of the results in a condensed form, the following brief summary has been appended. The conclusions listed here have been based upon data of the type cited in this paper.

(1) The density above and below the position of the disappearance of the meniscus is not the same for several degrees above the temperature at which the meniscus becomes invisible.

(2) The generalization expressed in (1) above, applies to experimental tubes filled to such an extent with liquid that the meniscus *either* rises or falls when the temperature is raised slowly from room temperature to the critical temperature. The unique condition where the meniscus neither rises nor falls seems to influence this density difference to such an extent that it completely disappears immediately at the critical temperature.

(3) A slight temperature gradient along the length of the bomb during the time of density measurements greatly alters the results. Sections (1) and (2) above are true under conditions of equalized temperature along the entire length of the bomb, checked to within $\frac{1}{50}$° C.

(4) By artificially creating a temperature gradient, such that the bottom of the bomb is about $\frac{1}{10}$° C. warmer than the top, the density within will equalize over a period of 40 to 50 min. while the same bomb at equal temperature top and bottom will not show any indication of equalizing the density over periods of four or five hours accompanied by vigorous stirring.

(5) By increasing the temperature at the bottom by $\frac{1}{5}$° C. over that at the top, a complete reversal of densities will be obtained in which the medium at the top has apparently a greater density than the material at the bottom. This condition will maintain itself in spite of vigorous stirring of the contents for indefinite periods of time.

(6) By artificially causing the top of the bomb to become heated to $\frac{1}{5}$° C. warmer than the bottom, the condition outlined in Section (1) will be accentuated.

(7) Once a condition of equal density throughout the bomb has been obtained in the manner outlined above, then a return to uniform temperature will not in any way alter the density conditions within the bomb.

(8) Upon *slowly* cooling the entire bath when a condition of uniform density prevails, the fog formation is exceptionally pronounced and no meniscus appears until the temperature has fallen about $\frac{1}{2}$° C. below that at which the meniscus disappeared with a rising temperature.

(9) Vigorous stirring of the contents has no effect upon the final density obtained and very little effect upon the rate with which it is reached.

(10) The rate at which the equilibrium density value is approached increases markedly with the extent to which the temperature is in excess of the critical value.

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THE DISCONTINUITY IN THE ADSORPTION OF GASES, VAPORS, AND LIQUIDS ON SOLID SURFACES AT THE CRITICAL TEMPERATURE UNDER CRITICAL PRESSURE: SYSTEM PROPYLENE-ALUMINA[1]

BY H. E. MORRIS[2] AND O. MAASS[3]

Abstract

An apparatus and a technique for studying the adsorption of gases, vapors and liquids on solid surfaces are described. The arrangement permits investigations in the region of the critical temperature and the critical pressure. Results with the system propylene and alumina are given. Adsorption from the gas and vapor phases indicates the formation of a surface complex which is unstable at low pressure and high temperature. The density of the adsorbed phase is greater than that of the bulk phase. There is no discontinuity in adsorption processes with a change from vapor state to gaseous state. No evidence was obtained of an increase in critical temperature on the surface of the solid. Adsorption does not occur from the liquid state, and there is a marked discontinuity in the adsorption curve with a change from liquid state to gaseous state. This is probably due to a change in the forces of attraction between liquid molecules and the solid as compared with the attraction between gaseous or vapor molecules and the solid surface. If this is the case it is further evidence for the discontinuity in the region of the critical temperature, which has been previously observed in other experiments in this laboratory.

Introduction

The sorption of gases, vapors and liquids upon solid surfaces has been extensively studied but in the majority of cases the measurements have been made at relatively low pressures, owing primarily to the experimental difficulties involved in all work under pressure. As evidenced by a recent symposium upon adsorption (6), there is much controversy and uncertainty regarding some of the most fundamental concepts of the phenomena. This is particularly true of the sorption of vapors and the nature of the adsorbed phase. Hence it is evident that any system which permits an examination of these problems should yield results of theoretical significance. The main reason, however, for the investigation to be described was to discover whether there exists a discontinuity, at the critical temperature and under the critical pressure, in the properties of a substance, such that this discontinuity might be made apparent by sorption measurements.

The possibility of the existence of a discontinuity of state under critical temperature conditions seems necessary to explain the discontinuity of reaction velocity discovered in this laboratory (21). A whole series of investigations was started in consequence of this work. One by Winkler and Maass (25) and another by Tapp, Steacie and Maass (22) have been published, and a third by Winkler and Maass will appear shortly. In these papers the question of "discontinuity" and its consequences on some of the properties of a system are referred to in detail.

[1] *Original manuscript received February 28, 1933.*
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Experimental

The apparatus of McBain and Britton (14), while admirably adapted for their purpose, could not be used by the writers in the form described. It was necessary for the object in view to have greater flexibility in immersing the sorbent at will in either compressed vapor or compressed liquid of the sorbate. Furthermore the temperature of liquid and vapor had to be kept at definite values without an intermediate indeterminate region. Hence although the success of the experiments was altogether dependent on that excellent instrument, the McBain-Bakr balance (13), the experimental arrangement was different from that of McBain and Britton and therefore deserves a somewhat detailed description. This is especially so since the results will have to be evaluated in the light of the density determinations of Winkler and Maass (26) and their data can be applied only to the form of apparatus described by the authors.

The Selection of a System for Study

There are a large number of solids which have been extensively studied as adsorbents, of which charcoal, silica and alumina are the most important. In view of the fact that one purpose of this study was to determine the effect of pressure, alumina was the solid employed. The selection of a sorbate which could vary through the phases of gas, vapor and liquid within a reasonable temperature range, and at pressures consistent with their use in glass bomb tubing, had been previously made in this laboratory. Propylene with a critical temperature of 92.3° C. and a critical pressure of 46.2 atm. seemed to be the most suitable for study in this apparatus. Dohse and Kälberer (5) studied the system propylene-bauxite from 0–120° C. but up to pressures of only 5 mm.

Description of Apparatus

The apparatus to be described permits a study to be made of the above system over a wide range of temperature in so far as the temperatures of both the gel and the phase being studied are concerned, and can be varied to a considerable degree. It also permits an actual study of sorption in the condensed phase, after the gel has been completely immersed in liquid. It is also believed that this system presents a much more effective method of temperature control than that of McBain and Britton (14), a factor which is of utmost importance in such studies. Furthermore it would seem that, in view of the known heat conductivity of thick Pyrex glass, the absolute control of the temperature would be rather difficult in the method used by these workers. In such a system a very slight temperature gradient along the bomb would markedly affect the pressure in the system.

The arrangement of the apparatus is shown in Fig. 1. The bomb *ABC* was made of special Pyrex bomb tubing with a bore of 12 mm. and 2–3 mm. wall thickness. A perforated aluminium basket was filled with alumina and suspended from the bottom hook of a carefully calibrated quartz spiral.

The spiral was hung by a glass hook from a Pyrex stirrup, held in the tube by small indentations in the wall of the bomb. The arm containing this suspension was connected by a capillary tube to the bomb containing the propylene to be adsorbed. This capillary *B* was wound with resistance wire to maintain the glass at a temperature slightly above that of the propylene to prevent condensation of the latter. A thermometer bent at right angles was placed between the wire and the capillary to determine the temperature of the latter. In what follows the side containing the suspension will be designated the gel side, and that with the liquid will be called the bomb side.

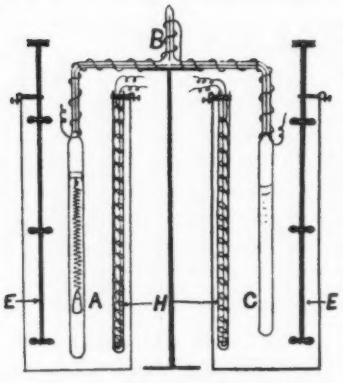

FIG. 1. *Diagrammatic sketch of high pressure sorption apparatus.*

The bath surrounding the gel side consisted of a large Pyrex jar which may be filled with any suitable liquid, transparent enough to permit readings of the extension of the spiral with a cathetometer. Butyl phthalate was found to be the most suitable for this purpose as it did not darken at high temperatures.

As a precautionary measure the bath surrounding the bomb side was made from a 6-in. iron pipe, lagged to prevent heat radiation. For low pressure studies the temperature of the propylene was maintained by carbon dioxide-acetone mixtures in a Dewar flask. This permitted very exact control of temperatures. The large baths were electrically heated as shown at *H*. It was necessary that there be no temperature differential in the baths hence the stirrers *E* had to be very effective. The temperature of the gel bath was read with a calibrated thermometer, while that of the bomb was read with a five-junction chromel-alumel thermocouple.

There is considerable danger attached to the study of high pressure phenomena in glass tubing, and for this reason the whole apparatus was enclosed in a heavy wooden case, strapped with band iron, and containing two windows of shatter-proof glass. The cathetometer for measuring the extension of the spiral was placed about four feet from the apparatus behind another sheet of heavy plate glass.

Thus an apparatus has been devised which permits the study of the sorption under pressure of gases, vapors and liquids. By the elevation of the temperature of the sorption bath above the critical temperature of the phase being sorbed, it became a study of gaseous sorption regardless of the pressure. Below the critical temperature, at pressures corresponding to the vapor pressure of propylene, the system becomes a vapor sorption study; while by raising the vapor pressure of the propylene, liquid may be condensed on and around the gel and the latter completely immersed if so desired.

Preparation for an Experiment

The spiral used in these experiments had a sensitivity of 0.00365 gm. per mm. and a maximum load of about 0.5 gm. Obviously the weight of the gel plus pan plus adsorbate could not exceed this latter value. The gel was prepared as described by Munro and Johnson (15), and a consideration of their results together with those of Perry (18) indicated that a maximum increase in weight of about 25–35% might be expected. Alekseevskii (1) found that alumina ignited to 600–620° C. gave the optimum sorption of ethylenic hydrocarbons; this gel was heated to 600° C. in a muffle furnace. It was then placed in the bomb, and the latter was connected through the capillary *B* to a high vacuum pump and the gel again heated to 400° C. under high vacuum. In this operation care was taken not to expose the spiral to this temperature in view of the observation of McBain and Britton (14) that the sensitivity of the spiral was changed upon subjection to such a temperature.

Pure propylene was prepared by the dehydration of isopropyl alcohol over alumina at 300° C. and purified by low temperature fractionation as described by Maass and coworkers (3, 10, 11). The purity of the propylene was checked by vapor pressure measurements during fractionation. The bomb was evacuated and the system flushed several times with propylene vapor, following which liquid propylene was condensed in the bomb using a carbon dioxide-acetone mixture, and the capillary was sealed off.

Zero sorption was found by freezing the propylene in liquid air while the gel was maintained at 95° C. The actual weight of the gel was found to be 0·32957 gm.

Experimental Results

The presentation of the results requires very little comment. Sorption is indicated in the usual form of x/m, in which x is the weight of material adsorbed and m the weight of the gel. This factor shows the weight of propylene sorbed per gram of alumina. With the exception of the region in which condensation to the liquid phase was approaching, the sorption equilibrium seemed to be attained almost immediately. In all cases however the readings were checked for a period of time to ensure a constant value. Points on the isobars were checked occasionally to be certain the zero value of the gel was not changing with time.

Pressure was determined by the vapor pressure of propylene. At low temperatures the values of Maass and Wright (10, 11) were used; at higher temperatures the data of Francis and Robbins (8) were used, as it checked with recent determinations in this laboratory.

Since this was a gravimetric method the density of the medium surrounding the suspension was of vital importance in correcting for buoyancy. The values at high pressures were particularly well known from the work of Winkler and Maass (26) and in this region the corrections were of greatest magnitude. At lower temperatures the factor was not as large but the values

were not as well known. Data of Ormandy and Craven (16) were employed and points in the intermediate range found by interpolation of the curve. One assumption was made, *i.e.*, that the density varied normally over short temperature ranges when the pressure was constant. To some extent this may be unjustified but the deviation would be too small to materially alter the ensuing calculations.

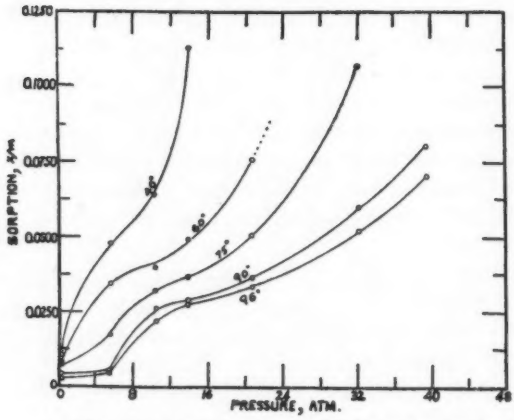

FIG. 2. *Isotherms showing the adsorption of propylene gas and vapor on alumina. Temperatures in ° C.*

Vapor-gas Media Surrounding Sorbent

It was most convenient to follow the process of sorption of gas and vapor by determining the isobars at increasing and decreasing temperatures of the sorbent, but one isotherm was determined to prove the adaptability of the system. The results are shown in detail in Tables I and II and more clearly in Figs. 2 and 3. The values in Table I have been selected from 190 readings for convenience in tabulation and indicate the course of the process quite fully. In Table II a few selected values indicate the magnitude of buoyancy corrections and show clearly the necessity of an accurate knowledge of the density of the phase, particularly at high pressures. In all cases the gel and the pan were considered together as sorbing material.

TABLE I

SORPTION OF VAPOR AND GAS ON GEL AT VARIOUS TEMPERATURES AND PRESSURES

Gel. temp., °C.	Pressure—atm.						
	0.2	5.7	10.5	13.9	20.7	32.1	39.4
	Sorption, x/m						
10	0.0291	0.0812					
20	0.0239	0.0591					
30	0.0156	0.0527	0.1372				
40	0.0130	0.0476	0.0596	0.1140			
50	0.0099	0.0402	0.0492	0.0656			
60	0.0076	0.0322	0.0396	0.0484	0.0746		
70	0.0078	—	0.0339	0.0387	0.0530		
75	—	0.0170	0.0318	0.0361	0.0492	0.1037	
80	0.0076	—	0.0298	0.0351	0.0454	0.0822	
84	—	—	—	—	0.0437	0.0697	
87	—	0.0086	0.0275	0.0304	0.0387	0.0640	0.0867
90	0.0041	0.0059	0.0265	0.0285	0.0361	0.0597	0.0794
93	0.0028	—	0.0233	—	—	0.0557	0.0742
97	0.0029	0.0047	0.0218	0.0269	0.0329	0.0512	0.0629
102	—	—	0.0192	0.0240	0.0307	0.0482	0.0585
107	—	—	0.0186	0.0228	—	0.0451	0.0536

TABLE II

INFLUENCE OF BUOYANCY AND ITS CORRECTIONS WITH INCREASING TEMPERATURE AND PRESSURE

Gel temp., ° C.	Vapor press., atm.	Apparent x/m	Vapor density, gm./cc.	Buoyancy correction	True x/m
19.7	0.2	0.0242	0.00035	0.0001	0.0243
29.7	5.7	0.0502	0.0094	0.0028	0.0530
38.0	10.5	0.0618	0.0170	0.0051	0.0669
47.7	13.9	0.0675	0.0238	0.0071	0.0746
63.7	20.7	0.0546	0.0374	0.0112	0.0658
82.4	32.1	0.0485	0.0808	0.0242	0.0727
90.2	39.4	0.0438	0.1172	0.0352	0.0790

Liquid-gas Media Surrounding Sorbent

The results obtained in the liquid-to-gas change require some elaboration. Two methods were employed: in the first, the bomb was held at a fixed temperature, 94° C. in one case and 100° C. in another, the gel was immersed in liquid and the temperature was raised slowly through the critical value while readings of the extension of the spiral were made. In the other method the gel was maintained above the critical temperature and the bomb temperature was again raised to 94° or 100° C.

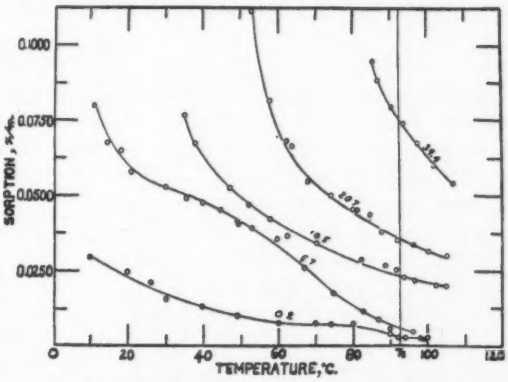

FIG. 3. *Isobars showing the adsorption of propylene gas and vapor on alumina. Pressures in atmospheres.*

Tapp, Steacie and Maass (22) and Winkler and Maass (26) observed that above the critical temperature the density of the gas in the bomb was not continuous but was a function of the previous history of the bomb. Thus they found that the density of the medium below the point at which the meniscus disappeared was uniform, but greater than the density of the medium above this point, this also being uniform throughout. The above experimental procedure makes it possible to surround the sorbent with either of these phases at will. Typical calculations shown below illustrate this more clearly. It was anticipated that the rate of diffusion through the capillary might influence the rate of attainment of equilibrium values, particularly as the relative positions of the arms changed from top to bottom, these terms being used in a sense to correspond to top and bottom relative to the disappearance of the meniscus in a straight tube. Actually this lag was not particularly evident but might account for some of the slightly divergent points.

Examples of the calculations indicate the importance of the density corrections. In these experiments the weight of the sorbent was 0.4121 gm. In both these examples the eventual bomb temperature was 100° C. but the relative position of the gel changed from the top to the bottom of the system. Thus in the first case the bomb was maintained at 100° C. and the gel was surrounded by liquid and the temperature raised to 94.6° C. The measured extension was 11.253 cm. corresponding to an apparent weight of 0.4107 gm. Since the gel was in the bottom of the bomb the density of the medium was 0.2130 gm. per cc., giving a correction of 0.0258 gm. and a net sorption of 0.0244 gm. or x/m equal to 0.0603.

In the second example the gel was maintained at 94.8° C. and the bomb raised from a lower temperature to 100° C. in which case the gel occupied the top of the system and the medium had a density of 0.2087 gm. per cc. The extension was 11.278 cm. corresponding to a weight of 0.4116 gm. The buoyancy correction was 0.0253 gm., giving a net sorption of 0.0248 gm. and x/m equal to 0.0613.

Selected values are shown in Tables III and IV and graphically in Figs. 4 and 5. In Fig. 5 Winkler's (26) density curve for propylene is plotted with

TABLE III

SORPTION OF LIQUID AND GAS; BOMB AT 100° C.

Gel at bottom				Gel at top	
Temp., ° C.	Sorption, x/m	Temp., ° C.	Sorption, x/m	Temp., ° C.	Sorption, x/m
68.2	−0.0005	93.4	0.0467	94.8	0.0613
71.2	−0.0015	94.4	0.0531	95.0	0.0591
76.6	−0.0017	95.3	0.0561	96.2	0.0586
79.3	−0.0010	96.6	0.0593		
81.4	−0.0002	97.6	0.0620	93.9	0.0620
87.1	0.0002	98.0	0.0633	94.2	0.0566
91.2	0.0077	98.3	0.0655	94.8	0.0551
92.2	0.0175	101.8	0.0633	95.8	0.0588
92.5	0.0242	110.2	0.0640	97.8	0.0611
92.9	0.0371	115.8	0.0665	99.6	0.0626
				*92.7	0.0445
				*91.7	0.0405

**Rapid cooling indicates a lag.*

TABLE IV

SORPTION OF LIQUID AND GAS; BOMB AT 94° C.

Gel at bottom				Gel at top			
Temp., ° C.	Sorption, x/m	Temp., ° C.	Sorption, x/m	Temp., ° C.	Sorption, x/m	Temp., ° C.	Sorption, x/m
88.0	−0.0022	92.7	0.0361	92.7	0.0704	107.5	0.0776
89.0	−0.0037	93.7	0.0628	94.8	0.0684		
90.1	0.0072	94.9	0.0756	96.6	0.0791	*95.3	0.0727
91.1	0.0040	96.0	0.0811	98.8	0.0786	*93.9	0.0702
91.7	0.0044	97.8	0.0808	101.2	0.0784	*92.8	0.0677

**Rapid cooling shows lag.*

the 94° C. sorption curve to illustrate the difference in type of curves, the significance of which will be discussed more fully later. It was observed that there were a few small irregularities, particularly when the gel was in the top of the system or on cooling. These were undoubtedly due to diffusion lags across the capillary but they were not of large magnitude. The hysteresis was not unexpected and the discrepancies practically disappeared with slow cooling.

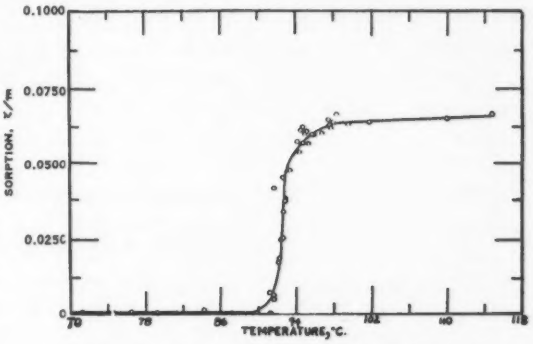

FIG. 4. *Curve showing the discontinuity in the adsorption of propylene liquid and gas on alumina. Bomb temperature, 100° C.*

There is one factor in the calculation of these curves which should be mentioned, that is, the influence of the change in bomb temperature from 94° to 100° C. It will be observed that the 94° C. curve shows a greater adsorption; this is due to the fact that at 100° C. the medium on the gel side would be more highly compressed and the buoyancy correction should be greater. Actually the influence of this compressibility was not known and therefore the same densities were used in both cases. It is anticipated that the true densities will be determined before the completion of this research, but for the present purpose this does not alter the conclusions which are to be drawn. It is expected that with the application of the corrected density values these curves will practically coincide, thus it will be observed that the values when both sides are at 94° C. in the one case, or at 100° C. in the other, are practically the same, lending support to this concept. Furthermore, when the corrections are made the adsorption curves above the critical temperature will tend to slope downward more markedly and follow a normal gaseous isobar.

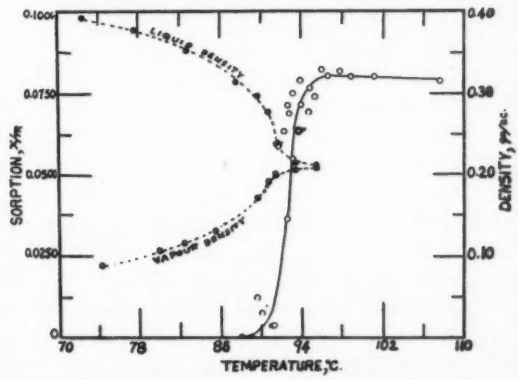

FIG. 5. *Curves showing the discontinuity in the adsorption of propylene liquid and gas on alumina gel. Bomb temperature, 94° C., and compared with Winkler and Maass' curves for the density of propylene.*

Discussion

The interpretation of these results presents many points worthy of consideration at some length and the more important of these will be discussed

in detail. In the calculation of results the following equation was used:

$$W = w + d_m v_g - w_o,$$

where W is the weight of adsorbed material, w the apparent weight of the gel, d_m the density of the medium, v_g the volume of the gel, and w_o the zero weight of the gel. Obviously the factor $d_m v_g$ represents the buoyancy correction.

It is at once evident that the volume of the adsorbed phase has not been considered. Hence the exact form of this equation should be developed as follows:

$$W_o = w + d_m v_g + d_m v_a - w_o,$$

where v_a is the volume of the adsorbed phase and W_o is the true weight of adsorbed material; $v_a = \frac{W_o}{d_a}$, where d_a is the density of this adsorbed phase. Hence the true expression becomes,

$$W_o = \frac{w + d_m v_g - w_o}{1 - \frac{d_m}{d_a}}$$

In this equation it is evident that if $d_m = d_a$, then $w + d_m v_g - w_o$, the measured value, becomes zero, hence $W = 0$, and furthermore W will have a positive value only when $d_a > d_m$. The meaning of this will be indicated later.

With regard to the density of the adsorbed phase, certain conclusions seem evident and these may remove some of the uncertainty regarding the nature of this phase. Thus Tryhorn and Wyatt (23) have measured the adsorption of organic vapors on porous substances and concluded from pore volume studies that the molecular volume of the adsorbed liquid was the same as that of the bulk liquid. On the other hand Dixon (4) assumed that the adsorbed gas condensed to a liquid whose density was greater than that of the normal liquid.

In studying the adsorption of a vapor above the liquid phase, if the adsorbed phase has the same density as the bulk phase, then adsorption would be measurable owing to the difference in densities of the media. However as the density of the vapor approached that of the liquid with a temperature increase, the adsorption curves should follow a form similar to that of the density curve and reach approximately a zero value at the critical temperature. It is evident that experimentally the latter is not the case and the adsorbed phase must have a greater density than that of the bulk phase. The density of the adsorbed phase, as represented by its concentration upon the surface, must decrease with temperature thus accounting for the form of the isobars.

Vapor-gas Media Surrounding Sorbent

The general form of the isotherms corresponds to an S-shaped curve similar to the adsorption of water vapor on cellulose. The interpretation of cellulose adsorption is that a surface corresponding to a monomolecular layer is formed with an increasing surface as sorption continues with a subsequent multi-

layer adsorption corresponding to the filling of capillary tubes (7, 9). In the cellulose-water vapor sorption curves the amount of adsorption at the same relative humidity is the same over a large temperature range. The same appears to be true of the isotherms of this alumina-propylene system, especially when account is taken of the fact that with the high pressure, and therefore high temperature isotherms, the true sorption values should be greater because the buoyancy of the adsorbed phase was not taken into account.

It is interesting to observe that the first part of the adsorption isotherms, which corresponds to a monomolecular layer forming a surface complex, requires increased pressure with a rise in temperature in order to be formed. There was no hysteresis which may be interpreted as an indication that there was no increase in surface with increased adsorption. Hence it would appear that the propylene first forms a surface compound with a subsequent filling of the capillaries, these latter portions of the curves being those in which the relative humidity relation holds. Consider the 40° and the 90° C. isotherms. In the former the S-shape starts at low pressure, in the latter the S-shape starts at about 5 atm. This is quite consistent with the idea that the first part of the adsorption process is a surface complex which dissociates at the higher temperature at low pressures and therefore requires the higher pressure values in order to be formed.

The form of the isobars also indicates this surface compound. At higher pressures the form indicates stability of the complex but the 5.7 atm. curve shows a marked change in form which is undoubtedly due to the high temperature dissociation of the surface form, which is quite stable at low temperatures and follows the normal form. It should be stressed that this curve was completely reproducible. The experiment was repeated several times and the curve plotted on each occasion to ensure that the form of the curve is as shown. At very low pressures the complex is not so stable but the slight discontinuities indicate its formation. Such curves have been obtained by other workers who also observed these reproducible discontinuities with other systems (2).

In the case of the cellulose-water vapor system, Filby and Maass (7) showed that water vapor sorbed on cellulose in the first part of the sorption isotherm has a density much greater than that of liquid water, assuming that the cellulose remains unchanged in density. Consequently it is not unreasonable to assume that in these curves the observed sorption in the first part of the curves at low temperatures corresponds to an adsorbed phase with a greater density than that of the bulk liquid under corresponding conditions. This point will be elaborated later.

It should also be pointed out that these curves are very different from those obtained under high pressure with charcoal as the sorbent. This is much as would be expected, according to McBain (12).

While the theoretical considerations of the behavior of vapors on solid surfaces have not been thoroughly elucidated, Rideal (20) and Polanyi (19)

have discussed the various factors and deduced two different forms of isotherm. The results with this system seem to favor the explanation of Rideal rather than that of Polanyi, but it would seem better at this stage to reserve a definite conclusion regarding this point.

It was stated that the main objective of this research was to investigate the question of a difference existing between molecules in the liquid and in the vapor or gaseous states, since the other investigations referred to indicated the existence of such a difference. No difference was to be expected however between molecules in the vapor or gas as defined by the critical temperature. That is, no discontinuity was to be expected in adsorption of gas or vapor at the critical temperature, but a discontinuity might be expected between adsorption from a liquid, and from a gas of density equal to that of the liquid. Whether the data obtained point to such a conclusion will now be discussed.

There is no discontinuity in adsorption in the change from vapor to gas as indicated quite fully by the regularity of the isobars (Fig. 3) through the critical temperature. Furthermore as shown by Fig. 2, isotherms plotted just above and just below the critical value are identical in form. It is thus evident that these may be considered as the same molecular species. The absence of an inflection in this regard has been interpreted by Patrick, Preston, and Owens (17) as indicative of an increase in the critical temperature of the sorbate in the capillaries. However in some of these cases the temperature was raised 15° C. above the critical value and it is unlikely that the capillaries could produce an effect of that order. Consequently there would seem to be no evidence for an increase in the critical temperature but rather it must be concluded that the adsorbed phase is not in the liquid or vapor state on the surface above the critical temperature.

Liquid-gas Media Surrounding Sorbent

The most striking feature of the change in adsorption from liquid phase to gas phase is the marked discontinuity at the critical temperature. There are several interesting facts revealed by a study of these curves. If no surface complex were formed with the liquid, and the adsorbed phase had the same density as the bulk phase, then obviously adsorption in such a system could not be measured. But this should also be true as the liquid phase changed to gas phase; in this latter case however sorption was measurable, indicating a difference in density between the bulk and adsorbed phases.

But if a complex were formed between the liquid and the sorbent it should be detectable (7). That this was not observed indicated that adsorption from the liquid phase did not occur, because as mentioned above, no adsorption means that $d_m = d_a$ and this would not be compatible with the results obtained in the region of the critical temperature. Thus the densities of the medium just above and just below the critical temperature are not very different but the amount of adsorption is markedly increased.

If for the purposes of discussion we assume an equilibrium between molecules from the liquid and the adsorbed phase below the critical temper-

ature, and also an equilibrium between the molecules of the gas and the adsorbed phase above the critical temperature; then it is evident that there is a discontinuity in that equilibrium at the critical value, as there is no indication of adsorption from the liquid while the gas is strongly adsorbed. Hence the molecules of the liquid state are not the same as those of the gaseous state.

The above interpretation seems to be the most reasonable at the moment but is admittedly dependent on considerations involving the buoyancy of the adsorbed material. Further investigations on adsorption are to be carried out with a view to its confirmation. If this should be confirmed, then, since adsorption is not observed from the liquid phase, the attraction of liquid molecules of homopolar character is greater than the heteropolar attraction between the liquid and the sorbent. This discontinuity at the critical temperature is due to the change in intermolecular attraction and in this case the force of adsorption is greater than the inter-attractive forces between the gaseous molecules. This discontinuity in character of liquid and gas is in accord with the behavior that might be expected from the previous investigations in this laboratory.

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THE EFFECT OF WINTER EXPOSURE IN THE STOOK ON QUALITY OF WHEAT[1]

By R. K. Larmour[2], J. G. Malloch[3] and W. F. Geddes[4]

Abstract

Samples of wheat were exposed in the stook over winter and threshed in the spring in two seasons. These spring-threshed samples were compared with check samples from the same lots that had been threshed in the fall. The exposed samples lost grade in 50% of the cases, and decreased in weight per bushel in practically all cases. The flour yield was generally increased slightly as a result of the winter exposure. In respect to baking quality 22% showed improvement and 40% showed damage. The changes in grade and bushel weight do not correspond very closely with changes in baking behavior.

Introduction

In some seasons, owing to unfavorable harvest conditions, a portion of the wheat in stook in western Canada becomes too wet to thresh and has to be left over winter and threshed in the spring. The percentage of this spring-threshed wheat is never large, but occasionally enough of it comes on the market to warrant question concerning its usefulness for milling and export.

This class of grain is characterized by bleached bran and starchy-appearing endosperm. The extent to which bleaching occurs will depend on the weather conditions during exposure and to some extent on the manner in which the grain is stooked. Under conditions necessitating spring threshing the grain will have been subjected to successive wettings and partial dryings, and the stooks, unless carefully made in the first place, may have settled badly with some of the sheaves lying on the ground. Such sheaves may undergo very serious damage from sprouting and from the growth of molds. The grain in the inside sheaves may escape damage altogether but on the other hand under some conditions it too may sprout or mold. When the weathering in the fall or spring has been severe enough to cause extensive sprouting or molding, the grain, if threshed, is generally considered unmarketable and usually is not offered for sale. If however late fall rains followed soon after by freezing weather is the cause of leaving the grain in the field for the winter, the drying in the spring is usually so rapid that little sprouting or mold damage is likely to occur. The appearance of the threshed grain is spoiled by the presence of a certain percentage of kernels which are more or less bleached. The effect of these is accentuated by contrast with the unbleached kernels in the sample. Furthermore the bleached grain when cut or broken shows a very white, starchy-looking interior similar to that of the soft winter wheats, and this

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similarity has given rise to the expression that such wheat "has gone starchy", the inference being that it has become degraded in strength.

It is extremely improbable that either bleaching or the change from vitreous to starchy appearance effects a material change in the strength of a wheat sample, provided other kinds of damage do not occur. Bleaching is concerned with the bran pigments and can be brought about by conditions that could not affect the strength. It is a common observation that ripe grain standing in the head awaiting the combine will undergo very severe bleaching from the effects of a light rain or even a heavy mist. In the ordinary process of tempering or conditioning preparatory to milling, much of the original bloom is lost and the grain may even appear somewhat bleached.

The change from vitreousness to starchiness seems to be associated with the fact that swelling occurs with wetting, and that this is not entirely reversible. Thus when wheat is brought to 18% moisture from a normal of about 11% the density, as indicated by bushel weight, decreases, and when the grain is dried back to its original moisture content of 11% the bushel weight does not come back to its original value but remains somewhat lower. This can be accounted for on the basis of the partial irreversibility of the swelling process, as a result of which larger air cells are left after drying. These air cells scatter the incident light and consequently the cross section appears whiter or less vitreous. Thus neither bleaching nor development of starchiness in themselves can be seriously considered as factors likely to affect in any way the inherent strength of a hard wheat, although it would appear quite possible that the latter change might be associated with some modification of the general colloidal characteristics of the endosperm. Saunders, Nichols and Cowan (4) showed that successive wettings resulted in an increase in loaf volume by the particular baking method used. This apparent increase in strength was also observed in a previous study of the effect of weathering on wheat (3) and was attributed to a sort of "mellowing" or "conditioning" effect which was apparent principally when the baking quality of the flour was tested by the simple formula. When, however, the bromate formula was used, this apparent improvement in quality nearly disappeared, indicating that no real change in inherent strength had occurred.

Despite these general conclusions regarding the likelihood of damage to strength by the factors discussed above, it was realized that commercial samples of spring-threshed grain might contain various percentages of severely damaged wheat, and it seemed desirable therefore to conduct some tests on samples that had undergone winter exposure under field conditions. To this end, samples of grain in the sheaf were collected in the fall of 1928 and of 1929. Each sheaf was divided carefully into two representative parts, one of which was threshed in the fall, the other being stooked in the field and left until spring. The samples obtained in this way will be referred to in this paper as the "fall-threshed" or "check" samples and the "spring-threshed" or "exposed" samples, respectively. The grain from each lot was divided into five-pound samples and sent to the collaborating laboratories for milling and baking tests.

Methods

The milling tests were made according to the flow-sheet given by Geddes (1), a straight flour of approximately 94% extraction being used in all cases.

The baking tests were conducted according to the procedure described by Geddes, Malloch and Larmour (2). Five different baking formulas were used, namely: (1) the simple or basic formula—flour 100 gm., yeast 3 gm., sugar 2.5 gm., salt 1 gm., water as needed; (2) the bromate formula—as (1) plus 1 mgm. of potassium bromate; (3) the blend-bromate formula—as (2) but using a blend of 40% of club wheat flour and 60% of the flour under test; (4) the malt formula—the simple formula plus 1 gm. of Panomalt; and (5) the malt-Arkady formula—the simple formula plus 1 gm. of Panomalt and 0.5 gm. of Arkady.

In compiling the data, averages of the results were taken when the tests were made in more than one laboratory. Such average values discount to a large extent the personal factor always present in wheat testing technique and are more reliable than determinations made in a single laboratory. The data thus obtained are too bulky for inclusion in a paper of this sort and therefor we shall present only summary tables and charts.*

Experimental Results

Effect of Exposure on Official Grade

Even though no damage to baking quality occurred, the bleaching of the grain might result in loss of grade which is a serious practical consideration. The data bearing upon this point can be summarized most readily by considering the numbers of samples in the various grades that were actually changed in grade as a result of exposure. These are shown in Table I. Of the 32 pairs of samples, three gained one grade, twelve were unchanged, nine lost one grade, and eight lost two grades. Of the eight samples that lost two grades, seven were No. 1 Northern in the fall.

TABLE I

CHANGES IN GRADE DUE TO WINTER EXPOSURE

Fall-threshed		Spring-threshed			
Grade	No. of samples	Gained 1 grade	Unchanged	Lost	
				1 Grade	2 Grades
No. 1 Hard	1			1	
No. 1 Northern	15		5	3	7
No. 2 Northern	6	2	1	2	1
No. 3 Northern	8		5	3	
No. 4	—				
No. 5	1	1			
No. 6	1		1		
Total	32	3	12	9	8

*The complete tables are on file with S. P. Eagleson, Secretary, National Research Council of Canada, and mimeographed copies are available to those interested in a minute study of the data.

Effect of Exposure on Weight per Bushel

The effect of exposure on weight per bushel is shown graphically in Fig. 1. Differences of less than one pound per bushel were not considered significant. On this basis six samples were unchanged in weight, fourteen lost 1 to 1½ lb., eight lost 2 lb. and three lost 3 lb. per bushel. One No. 3 Northern sample gained 1 lb. per bushel and lost one grade. Losses in weight were shown by 78% of the samples and it may be concluded therefore that generally there can be expected a material lowering of bushel weight when wheat is exposed in the stook during the winter. Indeed it is surprising that they all did not show decreases since wheat once thoroughly wetted will not regain its former density on drying.

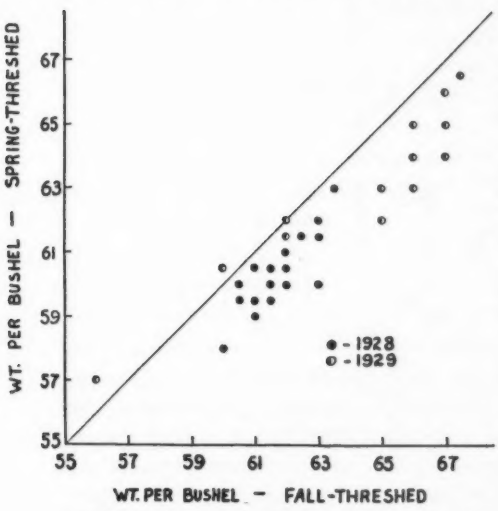

FIG. 1. *Comparison of fall- and spring-threshed wheat in respect to weight per bushel.*

Effect of Exposure on Flour Yield

For the summary of flour yield, values obtained by calculating the yield of straight flour from the spring-threshed sample as a percentage of the yield from the check sample have been used. The distribution of these is shown in Table II.

TABLE II

DISTRIBUTION OF VALUES FOR FLOUR YIELD

Fall-threshed		Spring-threshed as percentage of fall-threshed								
Grade	No. of samples	96–98	99	100	101	102	103	104	105	109
No. 1 Hard	1				1					
No. 1 Northern	15	1	2	2	1	4	2	2		1
No. 2 Northern	6	1	1		2	2				
No. 3 Northern	8	1	1		4	2				
No. 5	1			1						
No. 6	1								1	
Total	32	3	4	3	8	8	2	2	1	1

Twenty-two of the pairs gave higher flour yield from the spring-threshed than from the fall-threshed samples. This result is probably associated with the looser structure of the endosperm resulting from the successive wettings and dryings, a process which is somewhat analogous to conditioning prior to milling.

Effect of Exposure on Baking Quality

The absorption, or amount of water required to make the flour into a dough of the proper consistency, is important because it influences bread yield to a considerable extent. In this series the range of absorption was 62 to 68% and there were only two cases in which the spring-threshed samples showed higher values than the corresponding check samples. The distribution of the variations is given in Table III.

TABLE III

DISTRIBUTION OF CHANGES IN ABSORPTION

Fall-threshed		Spring-threshed compared to the checks, variations in actual percentages				
Grade	No. of samples	+1	Unchanged	−1	−2	−3
No. 1 Hard	1		1			
No. 1 Northern	15	1	6	4	3	1
No. 2 Northern	6		5		1	
No. 3 Northern	8	1	2	1	3	1
No. 5	1				1	
No. 6	1			1		
Total	32	2	14	6	8	2

The differences shown here are small but probably important. Assuming that 70% of the added water will be retained in the bread, a decrease of 2% in absorption would mean a decrease of 2.8 lb. of bread per barrel of flour.

TABLE IV

SUMMARY OF THE BAKING RESULTS

Number of cases in which	Baking formula						Total
	Simple	Malt*	Malt-phosphate**	Bromate	Blend-bromate	Malt-Arkady*	
Loaf volume							
Spring > fall	15	9	6	5	9	5	49
Spring = fall ± 2	13	7	4	12	8	4	48
Spring < fall	4	2	4	15	15	9	49
Texture							
Spring > fall	7	4	3	0	4	3	21
Spring = fall ± ½ point	21	9	9	23	16	11	89
Spring < fall	4	5	2	9	12	4	36
Crumb color							
Spring > fall	3	5	6	2	6	7	29
Spring = fall ± ½ point	26	8	7	19	10	7	77
Spring < fall	3	5	1	11	16	4	40
Baking score							
Spring > fall	15	8	7	7	6	6	49
Spring = fall ± 2	9	6	4	5	5	3	32
Spring < fall	8	4	3	20	21	9	65

*1928 series only. **1929 series only.

Factors, other than absorption, which have been considered are loaf volume, texture, crumb color and appearance of the loaf. Of these, the loaf volume is the most important especially in testing experimentally milled flours for strength because, with the exception of absorption, the other characteristics of bread are subject to a wide range of modification by means of variations in the formula. It is true that loaf volumes will also vary with the formula but theoretically, at least, there should be a maximum loaf volume for each flour that would depend only upon its inherent strength. The baking data have been summarized in Table IV. The formulas used fall into two classes, namely, those without and those with bromate. Table IV shows that in respect to volume and baking score, very little damage was apparent in the spring-threshed samples when they were baked by formulas without bromate. On the contrary, the simple formula indicated that in most cases the quality had been somewhat improved in most of the samples. Twenty-eight of the thirty-two exposed samples were equal or better than their checks as regards loaf volume. This is shown more clearly in Fig. 2 where the loaf volumes of the exposed samples are plotted against the loaf volumes of their checks. This observation holds also for the malt and the malt-phosphate formulas, although in these cases the writers have only a single season's results.

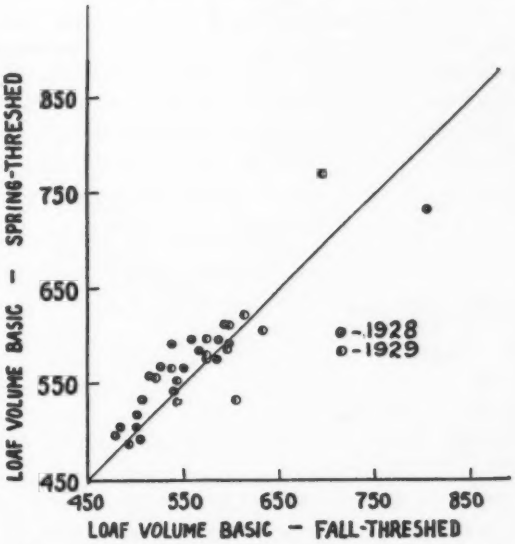

FIG. 2. *Comparison of fall- and spring-threshed wheat in respect to loaf volume by the basic formula.*

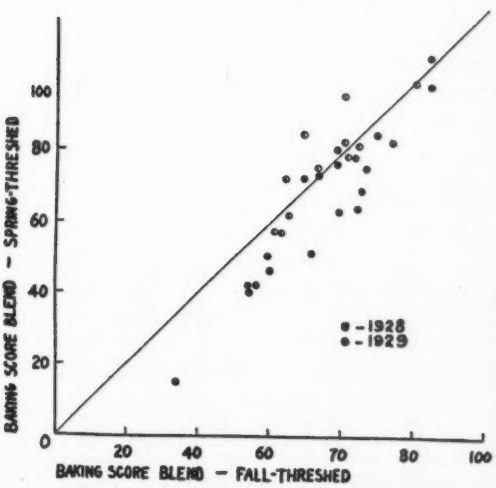

FIG. 3. *Comparison of fall- and spring-threshed wheat in respect to baking score by the blend bromate formula.*

It would be a mistake, however, to conclude from this that the winter exposure had resulted in an intrinsic improvement of quality, because on examination of the data obtained by the formulas including potassium bromate it is seen that in respect to both loaf volume and baking score, the exposed samples appear to be generally inferior to the fall samples. Thus by the blend-bromate formula 17 of the exposed samples were equal to or

TABLE V

SUMMARY OF THE 1928 AND 1929 TESTS

Loaf volume of the spring-threshed as percentage of the corresponding fall-threshed sample

Sample		Protein of wheat	Loaf volume S as % of F					Mean, no oxidizers	Mean, oxidizers	Change in grade F to S
No.	Variety		Simple	Bromate	Blend-bromate	Malt-phosphate	Malt-Arkady			
1928										
E 10		13.5	103	98	104	111	116	107	106	0
E 11		10.2	109	104	107	119	96	114	102	0
E 12		13.2	107	96	110	117	109	112	105	+1
E 13		10.6	111	102	96	136	104	124	101	−1
E 14		9.3	109	98	99	104	110	106	102	−1
E 15		10.8	104	87	95	102	97	103	93	−1
E 16		16.2	91	92	98	100	97	96	96	0
E 17		11.8	99	96	94	98	93	98	94	0
E 18		11.7	100	93	99	94	101	97	98	0
E 19		10.4	104	94	92	101	96	102	94	0
S 10	Marquis	13.0	98	94	92	92	106	84	102	−2
S 11	Red Fife	12.2	101	101	104	100	98	100	101	0
S 12	Red Fife	11.6	103	99	96	101	96	102	97	0
S 13	Marquis	10.6	104	102	95	102	96	103	98	−2
S 14	Marquis	12.7	101	104	101	104	108	102	104	−2
S 15	Red Fife	11.8	104	94	94	103	99	104	96	−1
S 16	Marquis	13.6	98	99	97	113	100	106	99	−1
S 17	Marquis	10.6	105	96	97	95	89	100	94	−2
Average								104	99	
1929										
E 50	Marquis	13.8	107	102	109	97		102	106	0
E 51	Garnet	15.2	102	90	102	103		102	96	0
E 52	Reward	12.7	100	89	105	93		96	97	0
E 53	Marquis	16.0	99	96	102	100		100	99	+1
E 54	Red Fife	15.4	101	99	101	97		99	100	0
E 55	Kitchener	14.7	101	120	100	97		99	110	+1
E 56	Garnet	15.8	101	99	104	111		106	102	−2
E 57	Marquis	14.5	110	102	103	105		108	102	−2
E 58	Renfrew	11.2	104	105	107	105		104	106	−1
W 1	Marquis	10.2	99	94	96	106		102	95	−1
W 2	Garnet	11.4	97	101	94	98		98	98	−1
W 3	Reward	14.5	96	106	97	100		98	102	0
W 4	Marquis	10.3	88	95	94	102		95	94	−2
W 5	Ceres	10.8	105	88	97	104		104	92	−2
Average								101	100	

better than their checks, while 15 were inferior, in respect to loaf volume, and in respect to baking score 21 of the 32 samples were inferior to the checks. This is shown graphically in Fig. 3 in which the blend-bromate baking scores of the exposed samples are plotted against the scores for the corresponding checks.

A more detailed treatment of the loaf volume results is given in Table V in which the samples of the two seasons are shown separately. The values are loaf volume of the spring-threshed as percentage of the loaf volume of the corresponding check sample. To facilitate comparisons, two means have been calculated for each sample, namely, the mean of the values obtained by the simple and malt-phosphate formulas, and the mean of the other formulas each of which included potassium bromate. By examining these two sets of means it should be possible to distinguish those samples which really were improved from those which were apparently improved but actually lowered in strength. If a sample showed improvement by both these sets of formulas, one would conclude that the improvement was real. When both sets show a decrease there can be little doubt that damage occurred. Considering only changes greater than 2% as significant, these results may be classified as in Table VI.

TABLE VI

DISTRIBUTION OF SAMPLES WITH RESPECT TO LOAF VOLUME

Number of samples showing:	1928	1929	Total	%
Improvement	4	5	7	22
No change	6	6	12	38
Damage	8	5	13	40

It is apparent from these figures that on the whole more samples were damaged than were improved. In 7 of the 13 damaged samples the average decrease in loaf volume by the oxidizer formulas was in excess of 5% while in the 7 samples improved, 4 showed an average increase in excess of 5%.

Conclusions

The effect of winter exposure on the quality of wheat may be summarized briefly in the following way:

The grade of the wheat was lowered in about 50% of the cases and the weight per bushel decreased in all but a very few instances. Flour yield was generally slightly increased but there occurred cases in which it was decreased.

The baking quality when judged by a formula including no oxidizer was usually improved but this appeared to be in many cases merely a kind of mellowing effect, because formulas with oxidizers in many cases showed decreased baking quality. In the series studied 38% of the samples exhibited no significant change, 40% evidence of damage, and 22% evidence of improvement as a result of the weathering they had received.

Of the 13 samples that showed evidence of damage due to weathering, 4 lost 2 grades, 3 lost 1 grade, and 6 were unchanged in grade. Altogether there were 8 samples that lost 2 grades. Of these 4 were damaged, 3 were unchanged and 1 was improved. There were 8 samples that lost 1 grade. Of these 3 were damaged, 4 were unchanged, and 1 was improved. Thirteen samples were unchanged in grade. Of these 6 were damaged, 5 were unchanged, and 2 were improved. The grade of the sample may be used as a rough criterion of change in baking quality, as in most cases where the grade is reduced, there is lowering of quality. It is not at all a dependable index of damage. It appears that the only safe criterion is a baking test of individual lots of wheat.

It should be pointed out, however, that the results brought out in this study very likely represent minimum effects. The outside storage of the samples took place in two seasons in which the autumn weather was quite dissimilar to the weather encountered in seasons when the farmers are forced to leave their wheat in the stook over winter. Under such circumstances the grain usually becomes thoroughly wet and is frequently subjected to a number of successive wettings and partial dryings before being finally frozen and snowed under. One might, therefore, reasonably expect to find that in a wet season the extent of damage by winter weathering would exceed the damage found in these two series.

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THE EFFECT OF AGING AND HEAT ON THE CHROMOSOMAL MUTATION RATES IN MAIZE AND BARLEY[1]

By F. H. Peto[2]

Abstract

The recent discovery by Navashin (3), that the chromosomal mutation rate in *Crepis* was influenced by aging of the seed, has been corroborated by observations on the mutation rate of corn plants grown from seed of various ages.

A very high chromosomal mutation rate in barley was induced by heat treatments of seed under various conditions of humidity. The most common type of aberration resulting from these treatments appeared to be fracture of the chromosomes either at the attachment constriction, the secondary constriction or the point of attachment of the trabants. The reattachment of fragments to other chromosomes was observed in two instances.

Considerable importance is attached to the discovery that a large proportion of the mutant cells are eliminated during the growth of the plant. The principle that *only the fittest survive* seems equally true of cells as of individuals and groups of plants or animals.

The Effect of Aging on the Mutation Rate

Navashin (3) reports that over 80% of the plants from seven-year-old seed of *Crepis tectorum L.* were chromosomal mutants of one sort or another while only 0.1% of the plants from fresh seed exhibited the same phenomenon.

The work outlined here was done in order to determine whether the above phenomenon was present in cereals grown from aged seed. Several inbred lines of maize were obtained from Professor L. C. Raymond of Macdonald College. Seed aged from one to six years of line II of this material was grown. In general there was a gradual decrease in germinability with the increase in age of the seed. There was a marked decrease in plant size and vigor in the plants from seed over a year old, and in addition a number of plants from seed lots over two years old were morphologically abnormal. Some were dwarfed and intensely green and died after reaching a height of a few inches; others were so heavily striped with chlorotic areas that they also died. A few of the more lightly striped plants survived but it is doubtful whether they will produce seed. A number of the chlorophyll-deficient plants resemble those produced when X-ray treatment was applied to corn by Stadler (5).

After the plants had been growing for two or three weeks root tips were obtained from 20 of each of six lots of seed of different ages. These were examined for chromosomal abnormalities after fixing with La Cour's 2BE fixative and staining with gentian violet. To date, results are available from three lots only. These are given in Table I and appear to corroborate Navashin's findings in *Crepis*. The remaining lines are being studied and any data collected will be presented in a later publication.

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Contribution from the National Research Laboratories, Ottawa, Canada. Issued as Paper No. 38 of the Associate Committee on Grain Research.
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TABLE I

EFFECT OF AGING ON THE MUTATION RATE IN MAIZE

Age of seed	Germination, %	Days from seeding to sampling of root tips	No. plants studied	Plants with mutated cells		No. cells observed	Mutated cells	
				No.	%		No.	%
6 months	92	22	20	0	0	120	0	0
5 years	76	32	19	3	16	112	5	4
6 years	32	33	20	5	25	155	13	8

Eighteen mutated cells were observed in plants from seed five and six years old. Seven of these cells contained 21 chromosomes, seven 19, one 18, two contained one fragment in addition to the normal number and one contained two complete sets of 20 chromosomes in the metaphase condition. These two nuclei were separated in the cytoplasm but within the same cell wall probably as a result of failure in wall formation after the previous somatic division. If this binucleate cell was also induced by aging it would indicate that all the mutants do not occur in the embryonic stage but throughout the life of the plant. The abnormal cells were located at random throughout the root tips, and it was impossible to find a large sector with all the cells exhibiting the same aberration. This indicates that most of the mutations were of relatively recent occurrence in the development of the root. Other mutations, however, may have occurred earlier in the embryonic and early seedling stage and subsequently have been eliminated. The reasons for suspecting this elimination will be considered later in this paper.

The Effects of Heat on the Mutation Rate

Crocker and Groves (1, 2) investigated the effect of storage and heat on seeds, and from the relation between the time-temperature formula for the coagulation of proteins and the temperature-life-duration formula for seeds concluded that the loss of viability of the seeds was largely a matter of the coagulation of the cell proteins. Since it has been shown that loss of germinability in seeds is associated at least in its more advanced stages with an increase in the mutation rate, it is logical to suspect that any abnormal environmental factor that would favor the denaturation or coagulation of the nuclear proteins might be expected to result in an increased mutation rate. Consequently a series of experiments involving the treatment of O.A.C. No. 21 barley seeds under various conditions of temperature and moisture have been undertaken and the preliminary cytological findings are given in Table II.

TABLE II

EFFECT OF HEAT ON THE MUTATION RATE IN BARLEY

Heat treatment	Germination	Material examined	No. plants studied	Plants with mutated cells		No. cells observed	Mutated cells	
				No.	%		No.	%
Untreated	99% in germinator	Root tips taken 30 days after seeding	12	0	0	41	0	0
95° C. for 25 min.	67% in germinator	Young seminal root tips	19	13	68	143	38	27
95° C. for 25 min.	67% in germinator, 32% in soil	Root tips taken 40 days after seeding	20	4	20	129	12	9
40° C. for 30 days	4% in germinator	Young seminal root tips	3	3	100	49	15	31

The barley was 1932 seed containing 9% moisture at the outset. In the treatment in a drying oven at 95° C. the seed was enclosed in a sealed glass capsule. There was a slight decrease in germinability after 15 min. heating. Further heating induced greater reduction in germination until at 35 min. the seed had lost its viability. There was a marked difference in the germination rate of seed placed in a Hearson's germinator and of that sown in soil. In soil the germination was lower owing probably to the less vigorous of the seedlings dying prior to emergence.

Of the seed treated at 95° C., only that exposed for 25 min. has been subjected to cytological examination. In one lot the seminal root tips were taken from the germinating seeds within a day or two after germination had commenced. In the other lot the root tips were taken from the plants 40 days after seeding. The difference in the mutation rate between these lots from seed treated in the same manner is very striking. There is a reduction in mutants from 68% in the seminal root tips to 20% in the plants 40 days after seeding. This indicates that there must be an elimination of the mutant cells during the development of the plant.

This is of great significance since it suggests that Darwin's principle of the survival of the fittest applies to cells as well as to individuals or groups of plants and animals. It suggests further that in plants grown under disadvantageous environmental conditions, there may occur a great profusion of mutant types, a large number of which for various reasons fail to survive for any length of time. The amount of initial variation which is induced is important, however, and while elimination of unfavorable mutants may take place earlier in the life of the plant than previously expected, any dominant or favorable mutants which might occur would undoubtedly have survival value.

No definite sectors carrying the same type of mutation could be found in the young seminal root tips. However, in the root tips from the older plants of the similarly treated seed, one large sector was found in which the same mutation occurred throughout, proving that this particular mutation had survived longer than those in the younger roots.

The chromosomal mutants observed in the barley heated at 95° C. consisted almost entirely of fragments. Approximately half of them were less than one-fifth of the average chromosome length. Some of these very probably had been trabants that had become disconnected from their chromosomes. The fractures resulting in the longer fragments appeared to have occurred in about equal numbers at the attachment constriction and secondary constrictions. In one instance a large fragment had become reattached to a normal chromosome.

According to Navashin's (4) dislocation hypothesis regarding the evolution of chromosome numbers, a fracture cannot occur at the exact point where the kinetic constriction (attachment constriction) is located. Nevertheless preliminary studies of the heat treated material indicates that fractures do occur quite frequently at this point. Further studies should supply more definite information.

Preliminary results are also given on barley seed treated at 40° C. in an open dish in an unventilated incubator. A large pan of water was placed in the bottom of the incubator so that the air must have remained close to the saturation point. The incubator was opened daily to prevent the air from becoming unduly stagnant. The percentage germination was reduced after five days treatment, and after 30 days treatment only 4% of the seeds remained viable. It was from three of these germinating seeds that the seminal root tips were taken. This was the most severe treatment applied and as would be expected the effects on the chromosomes were most pronounced. In addition to the types of fragmentation observed in the barley, whole chromosomes were occasionally missing, one cell contained only 11 chromosomes and two very small fragments.

These results show that the effect of heat on the chromosomal mutation rate is equally striking at low and high temperatures, providing adequate time is allowed for the treatment at the lower temperatures. This leads one to suspect that certain adverse environmental conditions in nature may be as effective in inducing changes in the chromosomal constitution of plants as is aging under natural conditions.

The evidence presented would appear to strengthen the mutationist's concept of evolution, but it indicates that the environment may play a large part in influencing the rate of mutation.

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THE MARINE ALGAE OF THE MARITIME PROVINCES OF CANADA

I. List of Species with their Distribution and Prevalence[1]

By Hugh P. Bell[2] and Constance MacFarlane[3]

Abstract

The marine algae of the Atlantic coast of the maritime provinces of Canada were collected at representative places all along the coast. The most intensive collecting was done at St. Andrews, New Brunswick, and at Halifax, Nova Scotia. An entire summer was spent collecting around Prince Edward Island. The report covers the work of more than seven years. The collecting was done chiefly during the summer, but regular collecting was also carried out for two winters. The area is divided into three distinct geographical and ecological regions, namely, the Bay of Fundy, the Atlantic, and the Prince Edward Island regions. In the list of species, their regional distribution and prevalence are given in tabular form. The list includes 120 species, divided into 30 Chlorophyceae, 41 Phaeophyceae, and 49 Rhodophyceae. In addition to critical notes regarding certain forms, the striking differences in the marine flora from region to region are indicated diagramatically by distribution maps for a number of species.

The following article is a statement regarding the occurrence, prevalence, and distribution of the more common forms of marine algae found along the shores of the maritime provinces. Workers in marine biology have often been in need of information of a general character regarding the distribution of the more common marine algae of this region, and as there is no up-to-date manual covering the forms found on the Canadian Atlantic coast, such information is difficult to obtain. This account is an attempt to provide the required information in an easily accessible form.

The original intention was to base this report on the results of intensive collecting at a limited number of points. However during the summer of 1927, Dr. Huntsman, of the Biological Board of Canada, instructed his workers throughout the maritime provinces to send in collections of seaweeds for identification in the Botanical Laboratories of Dalhousie University. From an examination of these collections it was at once apparent that there was great variation in the marine flora throughout the area and that it would therefore be necessary to carry out a more extensive program, including collecting all along the coast. It was not until the summer of 1931 that this program was completed. As a result the survey has extended over quite a number of years. Starting in 1924, two summers were spent collecting algae at St. Andrews, New Brunswick, four summers at the same work in Halifax, and one summer collecting at various points around Prince Edward Island. During the summers spent at St. Andrews and Halifax, numerous preliminary

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trips were made to other places, and in 1931 the coast of the maritime provinces was covered in a systematic manner. This was accomplished by numerous and extensive trips in a small car, and as a result collections were made at points all along the coast from Gaspé, Quebec, to Grand Manan, New Brunswick, inclusive. Most of the collecting stations are indicated on Map 2. To cover this ground and to visit the important stations a sufficient number of times necessitated over 8,000 miles of travel during the summer of 1931 alone. Although collections were taken on the shores surrounding the Gaspé Peninsula, this report does not cover that region, for the marine flora of that district is quite different from the flora of the New Brunswick and Prince Edward Island coasts. Bay Chaleur must therefore be regarded as the northern limit for the information given in this report. The possibility arose that a number of forms might occur only during the winter months. Such plants would have been missed in the summer collecting. In order to overcome this difficulty, regular and frequent observations were made at the mouth of Halifax Harbor during two winters. In spite of thorough search no winter forms were found which had not already been seen either early or late in the summer. Thus for the purpose of a preliminary survey of the common forms, the coast of the maritime provinces has been well covered.

In addition to the coastal regions, the warm Bras d'Or Lakes in the centre of Cape Breton were also investigated. The species there, though less plentiful than on the Atlantic coast, conform in a general way to those found in the latter region. But in the lakes the condition of the algae is so atypical and the ecological conditions so unlike those of the ocean that their discussion does not properly belong here and is left to a later paper.

For ease of reference the species listed are divided into the classes, Chlorophyceae (Greens), Phaeophyceae (Browns), and Rhodophyceae (Reds). In each class the species are tabulated alphabetically according to genera. The coast is divided by nature into three distinct geographical and ecological regions; namely, (1) the coast bordering the Bay of Fundy, (2) the eastern Atlantic coast of Nova Scotia, and (3) the coast of Prince Edward Island together with the coasts of New Brunswick, Nova Scotia, and Cape Breton, bordering on the Northumberland Strait and the Gulf of St. Lawrence. For convenience these are called the "B. of F. Region," the "Atlantic Region," and the "P.E.I. Region." The regional prevalence of each species is indicated by the self-explanatory terms, "abundant," "common" and "occasional." Their use in each case is not based on any actual counts. They are used merely to represent the general impression obtained regarding the comparative prevalence of the various species. When there was no record obtained for a species in one of the regions during this survey, the absence of such record is indicated by a blank. A blank space does not necessarily mean that the species is absent from the region, but it indicates at least that it is not very common there. It is desirable to record certain detailed information regarding some of the species. This is given in the form of notes immediately following the tables.

It should be explained that for some species the terms used to denote prevalence are not entirely satisfactory and in certain instances may not convey a correct idea. For during the course of this work one was much impressed by the rapid change which may occur in some species of marine flora. Plants of a certain species may be abundant in a given region for the greater part of a summer and not be seen there again for a long time. Or again, plants of some species may appear in great abundance for a few days only, but not be seen at all either before or after. In these individual cases, if observations had been made during a different year or at another time of the same year, a different term might have been selected to indicate the prevalence. But most species are not so variable or so perishable as this, and cases where observations suggest that a crop is of short duration are dealt with in the notes.

The dominant forms in the marine flora changed so abruptly from region to region that it was considered advisable to supplement the species list by distribution maps of a few species selected to illustrate typical differences. The occurrence of a species along any part of the coast is indicated by dots. The prevalence of a species is indicated by the dots being either close together, slightly separated, or quite far apart, indicating that the species is "abundant," "common," or "occasional." It will be noted from these maps that the prevalence of a species is fairly uniform throughout each region, but may change abruptly in going from one region to another.

When working with the marine algae of the Northwestern Atlantic, the works which one usually consults are those of Harvey (7, 8), Farlow (6), Collins (1, 2, 3, 4), Eaton (5) and Klugh (9). There is also a recent report for the extreme north of Cape Breton (St. Paul's Island) by Roscoe (11). In making identifications these works have been consulted continually. However, each of the authors mentioned above reports species for this region which are not mentioned in this article, for the present report is merely a record of observations made during this survey. Whenever possible the specific names used are taken from the list of marine algae published by Collins (1, 2, 3, 4). Those not included in Collins' list are made to conform to De Toni (13). Biological workers in the maritime provinces not familiar with the algae of the region would find a useful guide in "A Handbook of the British Seaweeds" by Lily Newton (10). This recently published handbook contains good keys and general descriptions, and it is well and copiously illustrated. Practically all the species found in the area considered here are described in this manual.

There are no Blue-greens or other microscopic forms included in this list, because this article deals only with conspicuous forms regarding which the average worker would require information, and the Blue-greens, etc., do not come under that head. There are however many species of Blue-greens to be found along the shores of the maritime provinces. Some of them form quite extensive gelatinous coatings over the surfaces of the rocks. Many others live as parasites or epiphytes on other algae. These blue-green plants are nearly all microscopic, and at present they are not likely to play a conspicuous part in non-botanical collections. They are therefore not included in the present report.

As far as could be ascertained from the records available the list that follows includes only two species which are reported for this area for the first time. These are *Monostroma arcticum*, Wittr. and *Stypocaulon scoparium*, (L.) Kuetx.

TABLE I

SPECIES LIST

Species	Bay of Fundy	Atlantic	Prince Edward Island	Map	Notes
CHLOROPHYCEAE					
Bryopsis plumosa, Ag.	—	Occasional	—		
Chaetomorpha aerea, (Dillw.) Kuetz.	—	—	Occasional		
Chaetomorpha aerea, (Dillw.) Kuetz. forma *Linum*, (Muell.) Collins	—	Common	—		
Chaetomorpha melagonium, (Web. & Mohr.) Kuetz., forma *rupincola*, Aresch.	Occasional	—	Occasional		
Chaetomorpha melagonium, (Web. & Mohr.) Kuetz., forma *typica*, Kjellm.	—	Common	—		
Cladophora crystallina, Kuetz.	—	Occasional	—		
Cladophora flexuosa, (Griff.) Harv.	—	Common	Common		
Cladophora flexuosa, (Griff.) Harv., forma *densa*, Collins	—	Occasional	—		
Cladophora gracilis, (Griff.) Kuetz.	—	Common	—		
Cladophora hirta, Kuetz.	—	Occasional	—		
Cladophora rupestris, (L.) Kuetz.	Occasional	—	—		
Cladophora virgatula, Grunow	—	—	Occasional		2.
Codiolum pusillum, (Lyngb.) Kjellm.	—	Occasional	—		
Enteromorpha compressa, (L.) Grev.	Abundant	Abundant	Common		
Enteromorpha intestinalis, (L.) Link, forma *clavata*, J. Ag.	Abundant	Abundant	Abundant		
Enteromorpha intestinalis, (L.) Link, forma *cylindracea*, J. Ag.	Common	Common	Common		
Enteromorpha linsa (L.) J. Ag.	Abundant	Abundant	Abundant		
Enteromorpha minima, Naeg., forma *glacialis*, Kjellm.	Common	Common	Common		
Enteromorpha percursa, (Ag.) J. Ag.	Occasional	—	—		
Enteromorpha prolifera, (Muell.) J. Ag.	Common	Common	Common		
Hormiscia penicilliformis, (Roth) Fries	Common	Common	—		
Monostroma arcticum, Wittr.	Occasional	—	—		
Monostroma fuscum, (Post. & Rupr.) Wittr.	Abundant	Abundant	Common		
Rhisoclonium riparium, (Roth) Harv., variety *implexum*, Rosen.	Occasional	—	—		
Rhisoclonium riparium, (Roth) Harv., variety *polyrhisum*, Rosen.	Common	—	—		
Rhisoclonium tortuosum, Kuetz.	Common	Common	—		
Rhisoclonium tortuosum, Kuetz., forma *polyrhisum*, Holden.	Occasional	Occasional	—		
Spongomorpha arcta, (Dillw.) Kuetz.	Abundant	Abundant	Occasional	3.	
Spongomorpha spinescens, Kuetz.	—	Occasional	—		3.
Ulva lactuca, L., variety *rigida*, (Ag.) Le Jolis	—	Occasional	Abundant		4.
PHAEOPHYCEAE					
Agarum turneri, Post. & Rupr.	Abundant	Abundant	Common		
Alaria esculenta, (L.) Grev.	Abundant	Abundant	—	4.	
Ascophyllum mackaii, (Turn.) Holmes & Batters	—	Occasional	—		
Ascophyllum nodosum, (L.) Le Jolis	Abundant	Abundant	Occasional	3.	
Asperococcus echinatus, (Mert.) Grev.	—	Common	—		5.
Castagnea virescens, (Carm.) Thuret	—	Occasional	—		6.
Castagnea soriera, (Mohr.) Thuret	—	Common	—		
Chaetopteris plumosa, (Lyngb.) Kuetz.	—	—	Common		

TABLE I—*Continued*

SPECIES LIST

Species	Bay of Fundy	Atlantic	Prince Edward Island	Map	Notes
PHAEOPHYCEAE—*Concluded*					
Chorda filum, (L.) Stackh.	Abundant	Abundant	Common		7.
Chordaria flagelliformis, (Muell.) J. Ag.	Abundant	Abundant	Common		
Desmarestia aculeata, (L.) Lamour	Common	Common	Common		8.
Desmarestia viridis, (Muell.) Lamour	Common	Common	Occasional		
Desmotrichum undulatum, (J. Ag.) Reinke	—	Occasional	Abundant		
Dictyosiphon foeniculaceus, (Huds.) Grev.	Common	Common	Abundant		
Ectocarpus confervoides, (Roth) Le Jolis	Abundant	Abundant	Abundant		9.
Ectocarpus tomentosus, (Huds.) Lyngb.	—	Occasional	—		9 & 10.
Elachistea fucicola, (Vell.) Fries	Common	Common	—		
Fucus evanescens, Ag.	Common	Abundant	Common		11.
Fucus platycarpus, Thuret	Common	Abundant	Occasional		
Fucus serratus, L.	—	Occasional	Abundant	5.	
Fucus vesiculosus, L.	Abundant	Abundant	Abundant		11.
Fucus vesiculosus, L., variety *sphaerocarpus*, Farlow	Occasional	Occasional	—		12.
Ilea fascia, (Muell.) Fries	Abundant	Abundant	Abundant		13.
Ilea rosterifolia, (Reinke) S. & G.	Occasional	Occasional	—		
Laminaria agardhii, Kjellm.	Abundant	Abundant	Abundant		14.
Laminaria digitata, Lamour	Abundant	Abundant	Common		
Laminaria longicruris, De la Pyl.	Abundant	Common	—	6.	15.
Laminaria phyllitis, (Stackh.) Lamour	—	—	Abundant	7.	
Mesogloia divaricata, (Ag.) Kuetz.	Common	Common	Common		
Mesogloia vermicularis, Ag.	—	—	Occasional		
Punctaria latifolia, Grev.	—	Abundant	Abundant		16.
Punctaria plantaginea, (Roth) Grev.	—	Occasional	—		
Pylaiella littoralis, (L.) Kjellm.	Abundant	Abundant	Abundant		
Ralfsia verrucosa, Aresch.	Common	Common	Common		
Saccorhiza dermatodea, (De la Pyl.) J. Ag.	Abundant	Common	Occasional	8.	
Sargassum sp.	—	Occasional	—		17.
Scytosiphon lomentarius, (Lyngb.) J. Ag.	Abundant	Abundant	Common		
Sphacelaria cirrhosa, (Roth) Ag.	—	—	Occasional		
Sphacelaria radicans, (Dillw.) Ag.	Common	—	—		18.
Stilophora rhizodes, (Ehrh.) J. Ag.	—	—	Common		19.
Stypocaulon scoparium, (L.) Kuetz.	—	—	Abundant	7.	
RHODOPHYCEAE					
Actinococcus subcutaneus, (Lyngb.) Rosenv.	—	—	Abundant	7.	20.
Ahnfeltia plicata, (Huds.) Fries	Common	Common	Common		
Antithamnion cruciatum, (Ag.) Naeg.	—	Occasional	Common		
Antithamnion floccosum, (Muell.) Kleen	—	Common	Occasional		
Bangia fusco-purpurea, (Dillw.) Lyngb.	Common	Common	—		
Callithamnion baileyi, Harv.	—	Occasional	Occasional		
Callithamnion corymbosum, (Sm.) Lyngb.	—	Occasional	—		
Callithamnion roseum, (Roth) Harv.	—	Occasional	Occasional		
Ceramium circinnatum, (Kuetz.) J. Ag.	—	—	Occasional		21.
Ceramium diaphanum, (Lightf.) Roth	—	—	Occasional		21.
Ceramium elegans, Ducl.	Common	—	—		21&22.
Ceramium rubrum, (Huds.) Ag.	Occasional	Common	Common		21.
Ceramium rubrum, (Huds.) Ag., variety *decurrens*, (Kuetz.) Harv.	—	—	Common		21.
Ceramium strictum, Grev. & Harv.	—	Occasional	Common		21&23.
Chondrus crispus, (L.) Stackh.	Occasional	Common	Abundant	9.	
Corallina officinalis, L.	Common	Common	Common		
Cystoclonium purpurascens, (Huds.) Kuetz.	Abundant	Common	Common		
Delesseria alata, Lamour	—	Occasional	—		24.

TABLE 1—*Concluded*

SPECIES LIST

Species	Bay of Fundy	Atlantic	Prince Edward Island	Map	Notes
RHODOPHYCEAE—*Concluded*					
Delesseria sinuosa, (Good. & Woodw.) Lamour	Common	Common	Common		
Dumontia filiformis, (Muell.) Grev.	Common	Common	—		
Euthora cristata, (L.) J. Ag.	Common	—	Occasional		25.
Furcellaria fastigiata, (Huds.) Lamour	—	—	Abundant	7.	
Gigartina mamillosa, (Good. & Woodw.) J. Ag.	Abundant	Common	—	6.	26.
Gloiosiphonia capillaris, (Huds.) Carm.	—	Occasional	—		27.
Gracilaria confervoides, (L.) Grev.	—	—	Abundant		28.
Halosaccion ramentaceum, (L.) J. Ag.	Common	Abundant	—	10.	
Halosaccion ramentaceum, (L.) J. Ag., variety *gladiatum*, Eaton	Common	Occasional	—		29.
Hildenbrandtia rosea, Kuetz.	—	Occasional	—		
Lithothamnion spp.	Abundant	Abundant	Abundant		30.
Melobesia le jolisii, Rosan.	Common	Common	Common		
Nemalion multifidum, (W. & M.) J. Ag.	—	Occasional	—		
Petrocelis cruenta, J. Ag.	—	Occasional	—		
Phyllophora brodiaei, (Turn.) J. Ag.	—	—	Abundant	7.	
Phyllophora membranifolia, (Good. & Woodw.) J. Ag.	Occasional	—	Abundant		
Plumaria elegans, (Bonnem.) Schmitz	Occasional	—	Occasional		
Polyides rotundus, (Gmel.) Grev.	—	Occasional	—		31.
Polysiphonia elongata, (Huds.) Harv.	—	—	Common		
Polysiphonia fastigiata, (Roth) Grev.	Common	Common	—		
Polysiphonia harveyi, Bailey	—	—	Occasional		32.
Polysiphonia nigrescens, (Dillw.) Grev.	—	Common	Common		
Polysiphonia olneyi, Harv.	—	Occasional	Occasional		32.
Polysiphonia spinulosa, Grev.	—	—	Occasional		33.
Polysiphonia urceolata, (Lightf.) Grev.	Abundant	Common	Abundant		
Polysiphonia violacea, (Roth) Grev.	—	Abundant	Common		
Porphyra laciniata, (Lightf.) Ag.	Abundant	Abundant	Abundant		
Ptilota pectinata, (Gunn.) Kjellm.	Common	Common	Common		
Rhodochorton rothei, (Turt.) Naeg.	Common	Occasional	—		
Rhodomela subfusca, Ag.	Occasional	Abundant	Abundant		
Rhodymenia palmata, (L.) Grev.	Abundant	Common	Common		

Notes

1. *Bryopsis plumosa*. Found only in the warm waters of the Thrumcap lagoon at the mouth of Halifax Harbor.

2. *Cladophora virgatula*. When seen in the water this form was distinctly different from any other *Cladophora* of the region, and it was found a number of times at various places around Prince Edward Island. It conforms to the description of *C. virgatula* given by Collins, but, as he reports it from the West Indies only, there is naturally some doubt as to its being this species.

3. *Spongomorpha spinescens*. Found only at New Harbor on the north-eastern side of Mahone Bay, N.S.

4. *Ulva lactuca* var. *rigida*. Other reports give this form as being common for this entire area, but during the present survey although diligent search

was made for it, no plants have been seen in the Bay of Fundy, and but few on the Atlantic coast. It was not found in any exposed situation but it was very plentiful in the P.E.I. region at the heads of warm bays and estuaries.

5. *Asperococcus echinatus.* This form may occur in the other regions also. It is possible that in the B. of F. and the P.E.I. regions it may have been unnoticed among the *Scytosiphon lomentarius* of which there was a great quantity.

6. *Castagnea virescens.* This occurred in great profusion for a short period during one summer in the Thrumcap lagoon, Halifax Harbor, but it has not been observed in abundance elsewhere, and repeated search has failed to locate it again at Thrumcap.

7. *Chorda filum.* Most manuals on algae do not lay sufficient emphasis on the striking change which takes place in this plant during the spring and summer. In the early spring it is profusely coated with dark brown hairs, so that it appears to be encased in a coat of dark heavy fur. Towards summer, these hairs become transparent and begin to drop off, until in the late summer the plant is completely denuded and becomes thin and stringy in appearance.

8. *Desmarestia aculeata.* When attached this plant is covered with a thick coating of dark brown hairs. When washed up on the beach the hairs are lacking for they disappear very quickly when the plant is removed from its sublittoral habitat. The change in appearance is so great that it is sometimes difficult to realize that the black wire-like plant found on the beach is the same species as the brown velvety plant seen waving in the water below the low tide mark.

9. *Ectocarpus.* There are undoubtedly several other species throughout this area, but due to the abundance of *Ectocarpus*, the similarities in appearance of various species in the field, and the large area covered during the survey, it was not possible to make a thorough investigation of species of this genus.

10. *Ectocarpus tomentosus.* Identified only from Clam Bay, N.S.

11. *Fucus evanescens* and *F. vesiculosus.* In the P.E.I. region the plants of these two species are very small.

12. *Fucus vesiculosus* var. *sphaerocarpus.* Due to the small size of the type in P.E.I. the variety may have been overlooked in this region.

13. *Ilea fascia.* Branching plants of this species were observed toward the seaward end of the breakwater at Borden, P.E.I.

14. *Laminaria agardhii.* The various manuals or lists referring to the marine algae of this area include *Laminaria saccharina* as occurring here. But during the present survey, every type of *Laminaria* found has been carefully sectioned through both lamina and stipe, and no mucilaginous ducts could be seen. The common *Laminaria* of these waters was therefore identified as *L. agardhii.*

15. *Laminaria longicruris.* This alga is of more frequent occurrence than would appear from the amount found washed up on the shores after storms.

This is largely due to its habitat in deep quiet waters. By dredging in such places as the Northwest Arm, Halifax, N.S., the plants can be found in large quantities.

16. *Punctaria latifolia.* This form is frequently found in great abundance, but is spasmodic in occurrence. For a brief period during the summer farmers can be seen taking it up in cartloads to be used as fertilizer, but for the rest of the year it is entirely lacking in that locality.

17. *Sargassum.* Specimens of *Sargassum* sp. were brought in by Dr. A. W. H. Needler, from Lockport, N.S. He reported, "There was quite a bit of this on the beach at Lockport on October 30, enough I would say to make it easy for one to get several bushels of the fresh weed in half an hour. The next day it had almost entirely disappeared, its place being taken by Fucus . . . ." This is the only time *Sargassum* was observed in this region, and due to the dried state of the plants when received it was impossible to distinguish the species.

18. *Sphacelaria radicans.* Collected only at the mouth of the Bay of Fundy.

19. *Stilophora rhizodes.* This was found in great quantities in warm landlocked tidal estuaries on the north shore of Prince Edward Island, especially at Bayview. It probably occurs in similar habitats elsewhere.

20. *Actinococcus subcutaneus.* Doubt has been cast on the validity of this species. Rosenvinge (12) declares it to be an asexual generation of *Phyllophora brodiaei* growing parasitically on the sexual generation. Similarly, concerning another species of *Actinococcus*, a note by Newton (10, p. 413), states in part, "Miss B. D. Gregory, permits me to quote her unpublished work, which has established the fact that the pustule, formerly referred to the genus *Actinococcus* Kutz., and believed to be parasitic on *Gymnogongrus griffithsiae* Mart., is actually the tetrasporic nemathecium of the *Gymnogongrus.*"

21. *Ceramium.* The classification of the species of this genus is in an unsatisfactory state at the present time, hence there is some doubt as to the nomenclature of the species here named, except in the case of the most common forms.

22. *Ceramium elegans.* Collected only at the mouth of the Bay of Fundy. It occurs in exposed situations only and grows in clumps that hang from rocky ledges. It is usually covered by other algae.

23. *Ceramium strictum.* Found only in very warm waters such as Souris beach, estuaries at Malpeque, Bayview, Lot 40, etc., P.E.I., and at Caribou Harbor near Pictou, N.S.

24. *Delesseria alata.* Only one specimen of this was found. It was obtained by dredging in Halifax Harbor.

25. *Euthora cristata.* Found at the mouth of the Bay of Fundy and on the north shore of Prince Edward Island. When observed it was in great abundance, but it occurred at infrequent intervals.

26. *Gigartina mamillosa.* On the Atlantic coast this form is local in distribution. Around the Bay of Fundy shores it is of more general distribution, and in places such as Sandy Cove near Digby it forms a thick mat over the flat surfaces of the rocks.

27. *Gloiosiphonia capillaris.* This is a transient form occurring for a few weeks in the summer, and has been found at only one spot near the mouth of Halifax Harbor. It has, however, been collected at the same time during two consecutive summers, and though a transient it would therefore seem to be a regular form for Halifax.

28. *Gracilaria. G. confervoides* has been found associated with *Stilophora rhizoides* in the warm waters of the landlocked tidal estuaries of P.E.I. The plants are heavy in structure, pale in color, and grow in bushy clumps. A part of a plant of *Gracilaria* sp. was also found washed upon the beach at the mouth of Halifax Harbor.

29. *Halosaccion ramentaceum* var. *gladiatum.* In the early spring the *Halosaccion* shows the typical wire-like cylindrical structure and compressed cartilaginous texture. A few weeks later in certain regions some plants can be seen to become gradually inflated or broad and flat. At the same time they become much softer and grow quite long (from about 8 in. winter length to 18 in. in spring). It is therefore doubtful whether this is a true variety, or merely a summer condition for certain regions.

30. *Lithothamnion.* No attempt was made to identify the various species of *Lithothamnion* of which there are a great number in this area.

31. *Polyides rotundus.* The identification of this species is uncertain. No fruiting plants have been found.

32. *Polysiphonia harveyi,* and *P. olneyi.* Much doubt exists concerning these two species. They are all gradations from the slender *P. olneyi* to the setaceous *P. harveyi.*

33. *Polysiphonia spinulosa.* Only two small pieces of this were collected, and though searched for carefully, not enough could be found for complete identification.

Explanation of Maps

MAP 1.

Maritime provinces with the exception of northern New Brunswick, showing the area covered during the survey and the main regions to which reference is made in this article.

MAP 2.

Area covered by survey showing the principal collecting stations.

MAPS 3-10.

These maps indicate the sharp change in marine flora from region to region. The presence of a species is indicated by dots along the part of the shore where it was collected. Their abundance is indicated by the relative distance between dots. In every case the species having the indicated distribution are listed on the map, and the map numbers are given in the species list.

Acknowledgments

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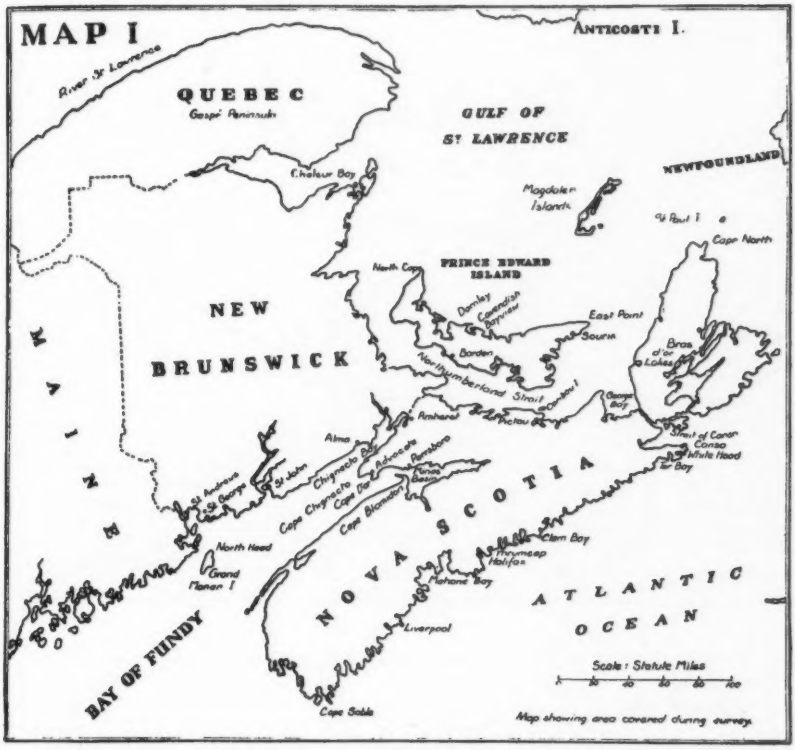
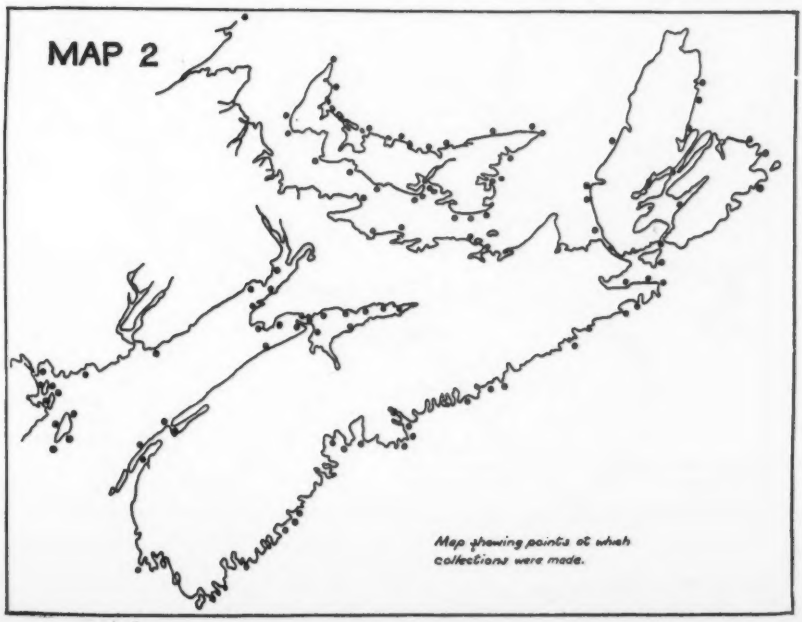
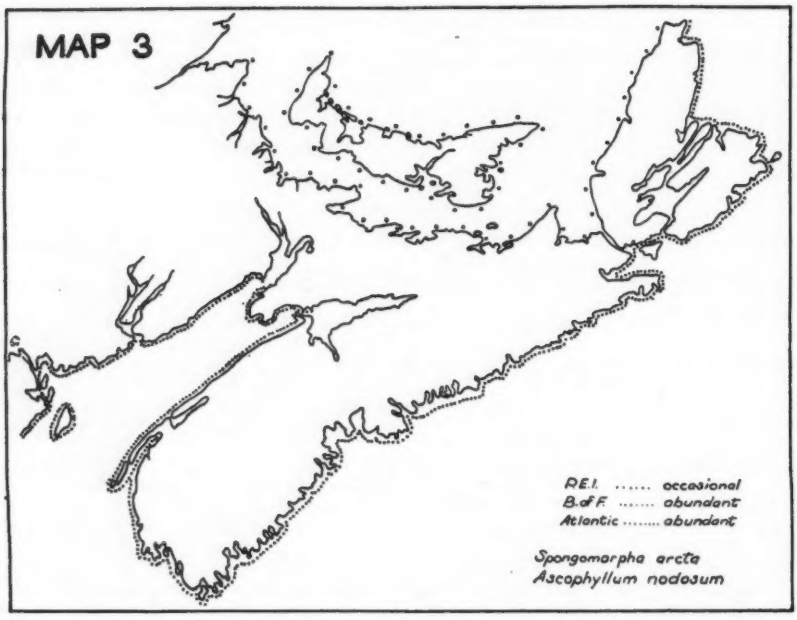
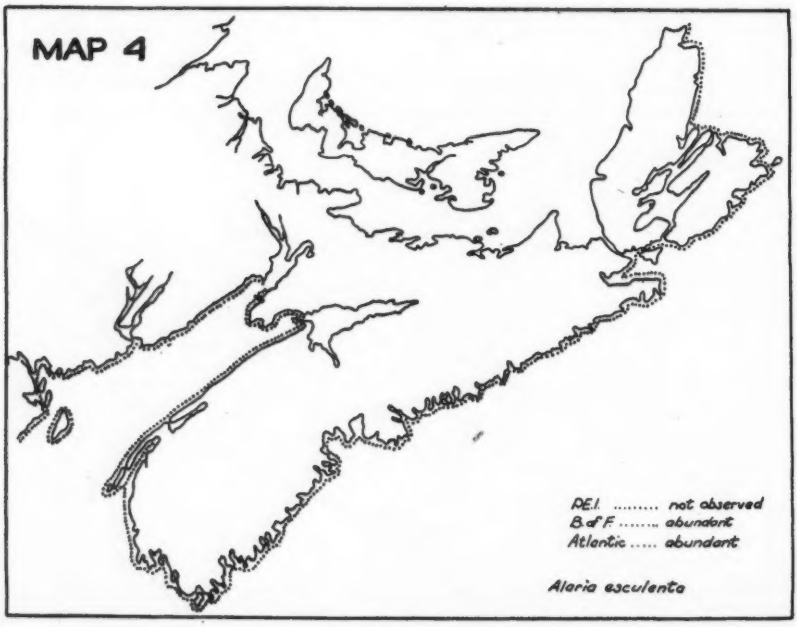
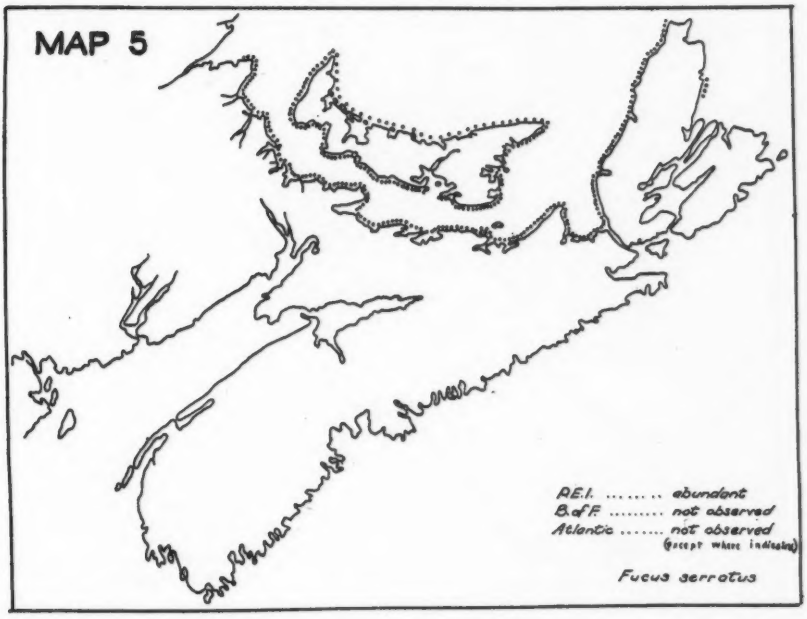
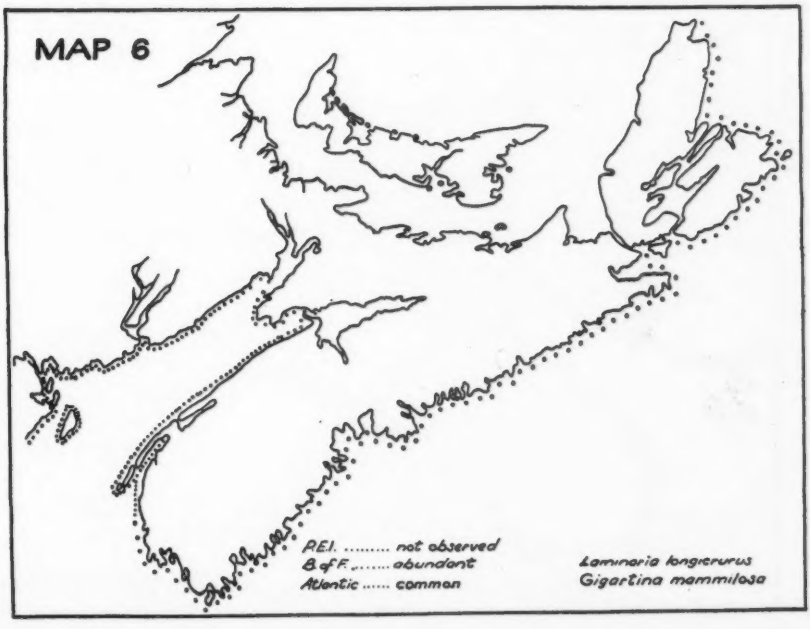

MAP I
River St. Lawrence
QUEBEC
Gaspé Peninsula
Chaleur Bay
GULF OF
St LAWRENCE
ANTICOSTI I.
NEWFOUNDLAND
Magdalen Islands
St Paul I.
Cape North
North Cape
PRINCE EDWARD ISLAND
Darley
Cavendish
Rustico
East Point
Souris
Bras d'or Lakes
NEW
BRUNSWICK
Border
Northumberland Strait
Pictou
Amherst
George Bay
Strait of Canso
Canso
Whitehead
Tor Bay
Alma
St John
Chignecto Bay
Cape Chignecto
Cape Tor
Advocate
Parrsboro
Cape Blomidon
Minas Basin
St Andrews
St George
North Head
Grand Manan I
BAY OF FUNDY
NOVA SCOTIA
Clam Bay
Prospect
Halifax
Mahone Bay
Liverpool
Cape Sable
ATLANTIC
OCEAN
Scale: Statute Miles
0 20 40 60 80 100
Map showing area covered during surveys.

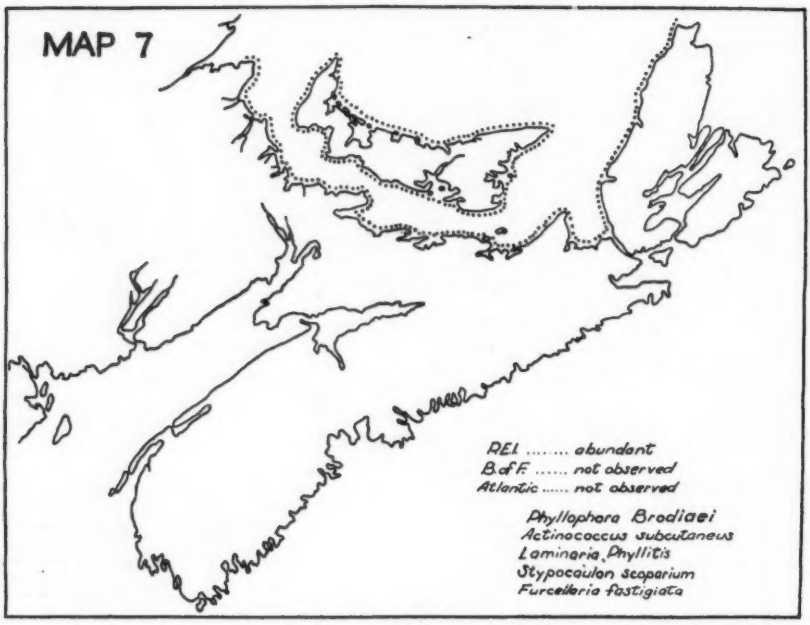

MAP 2
Map showing points at which collections were made.

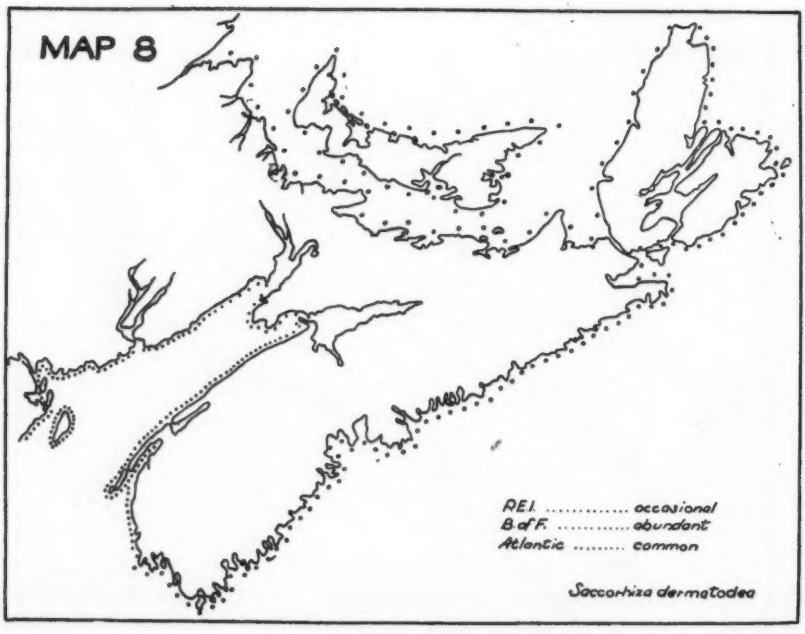

MAP 3
P.E.I. ..... occasional
B. of F. ..... abundant
Atlantic ..... abundant
Spongomorpha arcta
Ascophyllum nodosum

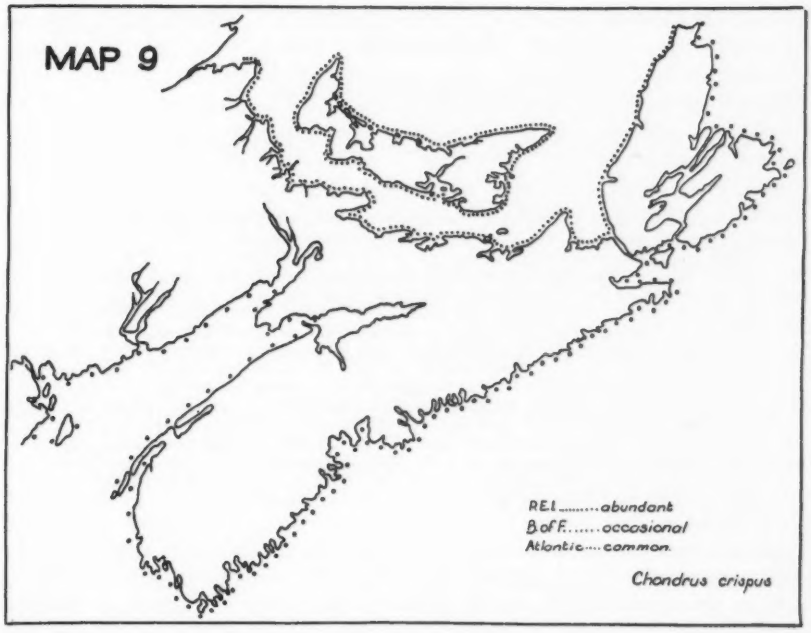

MAP 4
P.E.I. ..... not observed
B. of F. ..... abundant
Atlantic ..... abundant
Alaria esculenta

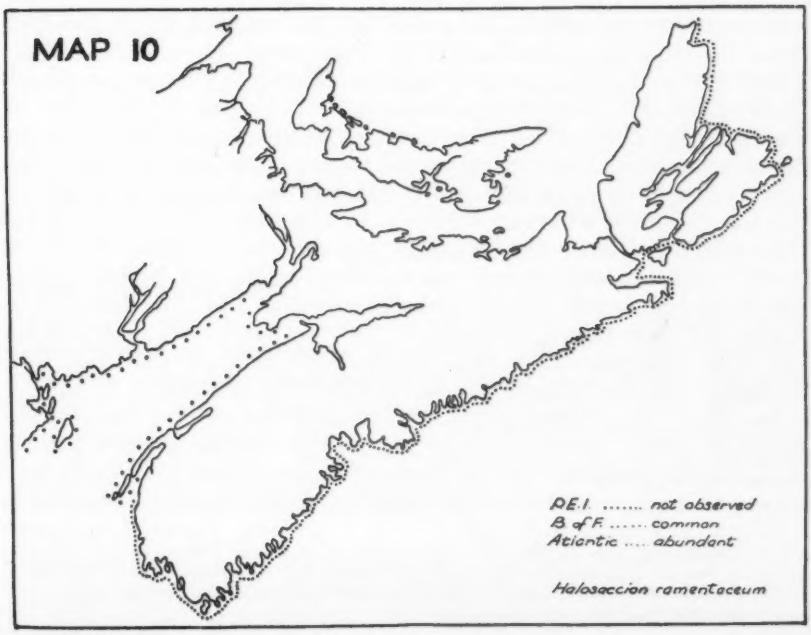

MAP 5
P.E.I. ..... abundant
B. of F. ..... not observed
Atlantic ..... not observed
(except where indicated)
Fucus serratus


MAP 6
P.E.I. ..... not observed
B. of F. ..... abundant
Atlantic ..... common
Laminaria longicrurus
Gigartina mammilosa


MAP 7
P.E.I. ..... abundant
B. of F. ..... not observed
Atlantic ..... not observed
Phyllophora Brodiaei
Actinococcus subcutaneus
Laminaria Phyllitis
Stypocaulon scoparium
Furcellaria fastigiata


MAP 8
P.E.I. ..... occasional
B. of F. ..... abundant
Atlantic ..... common
Saccorhiza dermatodea


MAP 9
P.E.I. ..... abundant
B. of F. ..... occasional
Atlantic .... common
Chondrus crispus


MAP 10
P.E.I. ..... not observed
B. of F. ..... common
Atlantic .... abundant
Halosaccion ramentaceum

THE MARINE ALGAE OF THE MARITIME PROVINCES OF CANADA

II. A Study of their Ecology[1]

By Hugh P. Bell[2] and Constance MacFarlane[3]

Abstract

The coastal area of the maritime provinces of Canada is divided into three regions, the Bay of Fundy, the Prince Edward Island, and the Atlantic. Each of these is distinctly different in regard to both marine flora and marine flora environment. The main features of the marine flora of each region are as follows: Bay of Fundy, generally dense and luxuriant; Prince Edward Island, a barren littoral zone and a rich sublittoral flora; Atlantic, intermediate in density and luxuriance with the predominance of large linear forms in the surf. With the exception of *Fucus vesiculosus* and *Ascophyllum nodosum* which are dominant in the littoral zones of both the Bay of Fundy and Atlantic regions, there are species dominant for each region and peculiar to it. The physical factors varying throughout the area, and associated with the floral differences are: water temperature, tides, wave action, clarity of the water as regards mud, structure and composition of the rocks along the shore, materials forming the ocean floor near the shore, slope of the intertidal zone, slope of the ocean floor near the shore, salinity, and ice action. Each of these physical factors is associated with certain characteristic features in the marine flora.

Marine algal associations have attracted the attention of algologists in many parts of the world, and have been discussed in many reports. Kjellman (10) in his report of the marine algae of the Arctic describes the various "formations." Cotton (2) gives a very clear picture of the formations and associations of the marine algae around Clare Island, Ireland. Others who have dealt with this subject in a similar manner are Hoyt (5) for Beaufort, N.C., U.S.A.; Johnson and York (9) for Cold Spring Harbor, N.Y., U.S.A.; Chater (1) for the Aberdeenshire Estuaries, Scotland; Johnson and Skutch (6, 7 and 8) for Mt. Desert Island, Maine, U.S.A.; Knight and Park (11) for the Isle of Man, England, and many more dealing with other parts of the world.

In comparison with these regions the ecology of the marine algae of the maritime provinces of Canada provides an even more interesting study, for this area is divided into three adjoining but distinctly different geographical and ecological regions. The regions are, (1) the coast bordering the Bay of Fundy, (2) the eastern Atlantic coast of Nova Scotia, and (3) the coast of Prince Edward Island together with the coasts of New Brunswick, Nova Scotia, and Cape Breton, bordering on the Northumberland Strait and the Gulf of St. Lawrence. As in Part I of this article these are called the "B. of F. Region," and the "Atlantic Region," and the "P.E.I. Region." In addition to the three main divisions of the area, there are the enclosed waters of the Bras d'Or Lakes. These salt water lakes exhibit conditions that are by no means typically marine, but the flora and physical conditions provide such striking contrasts, that they will be considered briefly. The unusual ecological

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situation that exists in the three main regions are well illustrated by Maps Nos. 3 to 10 inclusive, in Part I of this article. Throughout each region the flora is uniform in regard to dominant forms and character of growth, but each region is as distinct from the other as if separated by great distances and influenced by an entirely different climate and environment. A comparative study of the flora and its associated physical environment should reveal some important facts regarding the limiting factors in marine algal growth.

It is reasonable to assume that this distinct difference in the algal growth of each of the three regions is brought about by a difference in the physical environment in which the algae grow. As these regions are within a few miles of each other the general climatic conditions are similar, but other physical factors show wide variations. While collecting in each region an attempt was made to study the environment in which the algae were growing and to compare the environment of each region with that of the others. Certain important factors are uniform throughout the area, but many others vary extensively. Obviously it must be the latter which cause the difference in the algal growth of these three regions. The physical conditions that vary from one region to another are as follows; water temperature, tides, wave action, clarity of the water as regards mud, structure and composition of the rocks along the shore, materials forming the ocean floor near the shore, slope of the intertidal zone, slope of the ocean floor near the shore, salinity, and ice action. These factors are referred to in this same order all the way through the report, and are described in detail along with the flora for each region. The temperature quoted is that of the shore surface water of an exposed part of the coast, and represents the average temperature for the warmest months. Temperature and salinity are stated as approximations only and were calculated from the records in the possession of the Biological Board of Canada and from others given by M'Gonigle (12) in his report on the marine borers of the Atlantic coast of Canada.

Each region is described under the headings of general character of growth, dominant species, physical factors, and variations within the region.

Bay of Fundy Region

General Character of Growth

The most striking feature of the Bay of Fundy region is the density of the vegetation and the luxuriance of the growth. The littoral zone is covered by a thick continuous mat of plants that start abruptly as a horizontal line of growth just below the upper limits of the littoral zone. The plants themselves are large. Average plants of *Ascophyllum nodosum* are from 30 to 40 in. long and some in St. John Harbor were found to be six feet, six inches. All the other forms are correspondingly large.

Dominant Species

The dominant forms in the upper parts of the littoral zone on all parts of the coast, and throughout the whole littoral zone in the more inland portions of the bays are ***Fucus vesiculosus*** and ***Ascophyllum nodosum***. In the lower

littoral zone of all the more exposed parts of the coast the rocks are covered with a luxuriant growth of *Porphyra laciniata* and *Rhodymenia palmata*. The *Porphyra* plants are very large and dense in their form of growth, each one resembling closely a head of cabbage. Hanging from the crevices of the rocks and under the *Rhodymenia* plants are large bunches of a deep red *Polysiphonia urceolata*, and here and there extensive growths of *Cystoclonium purpurascens*. *Gigartina mamillosa* is abundant everywhere and in certain places forms a thick moss-like mat over the flat surfaces of the rocks. The most striking sublittoral species is the Laminaria which has so far been called *L. longicruris*, known locally as the "devil's apron." The plants of *Alaria esculenta*, *Desmarestia aculeata*, *D. viridis*, etc., are all exceptionally large. There are rich growths of *Euthora cristata* and *Ceramium elegans*, and dredging reveals extensive beds of such deep-water forms as *Delesseria sinuosa* and *Ptilota pectinata*. In the tide pools large sheets of *Monostroma fuscum* are to be found everywhere, as are also large plants of the usual tide pool forms such as *Scytosiphon lamentarius*, *Dictyosiphon foeniculaceus*, *Ilea fascia*, *Enteromorpha linza*, etc. *Chondrus crispus* also grows in the tide pools, where it has a broad frond quite unlike the narrow deeply divided fronds of deeper waters. It is important to note some of the plants that are not common in this region. They are the typical sublittoral *Chondrus crispus*, *Laminaria agardhii*, *Ulva lactuca*, *Polysiphonia violacea*, and *Ceramium rubrum*.

Physical Factors

The physical factors are typical of a body of water where there is a big regular tidal movement of water into a funnel-shaped bay. The temperature of the water is very low, the average shore surface temperature of an exposed part of the coast for the warmest month being from 50 to 54° F. A big tidal rise and fall occurs twice every 24 hr. At North Head, Grand Manan Island, at the mouth of the bay this difference between high and low tides is from 21 to 24 ft., and at Amherst Harbor at the head of the bay, from 43 to 47½ ft. As a result of this great movement of water there are very rapid tidal currents and a constant mixing of the water. The ocean roll is lacking and except after a storm there is comparatively little surf. In the main part of the bay the water is clear, but at the head of the bay and at the heads of the inlets, the water is turbid. The rocks that line the shore and extend out under the water are a soft sandstone. These rocks crop out at various places under the water, but the ocean floor near the shore consists largely of mud. There are however, many places with sand, gravel, or larger loose rounded rocks. As a rule the slope of both the intertidal zone and the ocean floor near the shore is very gentle, giving an extensive intertidal zone and a broad zone of fairly shallow water below the low tide mark. The salinity ranges from about 3 to about 3.2. Owing to the fact that the tides do not let the water remain still long enough to freeze, very little ice is formed in the bay or its inlets.

Variations Within the Region

There are certain variations within the bay that are very striking. Proceeding from the mouth of the bay towards the head, the marine flora gradu-

ally becomes less in quantity and less luxuriant in growth, until it finally disappears in the vicinity of Blomidon on the Nova Scotian coast and a few miles north of Alma on the New Brunswick side. There are, however, scattered patches of algae inside these points especially where there are outcrops of rock on the ocean floor. This includes such places as the shores in the vicinity of Parrsboro where the flora is comparatively rich. Another outstanding exception is the whole tongue of land between Minas Basin and Chignecto Bay. At Spencer Island, Cape d'Or, Cape Chignecto and all the other places around Advocate the flora is very rich, though not as rich as near the mouth of the bay. The most striking fact is that this flora at Advocate has a slightly different aspect, the *Chondrus crispus* for instance is present in its typical marine form, which is quite different from the broad form found at the mouth of the bay. The water at the head of the bay occasionally becomes quite warm, especially when the tide has risen just after noon over sun-baked mudflats. Disregarding these few exceptions, the head of the bay consists of extensive mudflats destitute of any form of algal growth, either littoral or sublittoral and the water is muddy and at times it may be warm.

Prince Edward Island Region

General Character of Growth

When it is considered that the Northumberland Strait is only about 15 miles due north from the head of the Bay of Fundy, the differences noticed in the marine flora of these two bodies of water are most striking. On the exposed parts of the coast throughout the whole P.E.I. region there is practically no algal growth in the littoral zone. In the bays and in the sheltered crevices all along the coast one finds stunted plants of *Fucus vesiculosus*, and here and there a few plants of *Ascophyllum nodosum*, but these plants are miserable and dwarfed specimens and to one accustomed to the rich B. of F. growth, they merely add to the barren appearance of the P.E.I. intertidal zone. One seldom finds either *Fucus vesiculosus* or *Ascophyllum nodosum* more than 8 or at the most 12 in. long. The only healthy forms forming a dense growth in this littoral zone are certain Greens that grow near the high water mark, such as small plants of *Enteromorpha intestinalis*. In contrast with this barren littoral zone there is usually a great quantity of loose weeds in the wash along the shore, and on examination it is found that there is a luxuriant sublittoral growth including many forms that are rarely found in other parts of the northwestern Atlantic.

Dominant Species

In view of these facts it is natural to expect that, in the P.E.I. waters, it is in the sublittoral zone that one finds the forms that give the region its distinctive character, and this actually is the case. On all the exposed parts of the coast there are extensive beds of the typically marine *Chondrus crispus*. The plants are large and comparatively free from epiphytic shellfish. This species grows in such quantities that it is washed up in great heaps all along the shore. An equally prominent form, but one that is found in localities

that are slightly less exposed, is *Fucus serratus*. The plants of this species occur in great abundance and are large and healthy. This is the only place from which it has been reported in the northwestern Atlantic. Other plants that are washed up in large quantities are, *Stypocaulon scoparium*, *Furcellaria fastigiata*, *Phyllophora brodiaei*, *P. membranifolia*, and *Laminaria phyllitis*. There are many others, but these are not only the most prominent, but occur in great abundance. It should be noted that none of these forms are common in either the B. of F. or the Atlantic regions. There are other forms that are not quite so abundant and yet are common for this region and either unknown or very rare in the other regions. These are *Chaetopteris plumosa*, *Gracilaria confervoides*, *Mesogloia vermicularis*, *Polysiphonia elongata*, *Stilophora rhizodes* and *Antithamnion cruciatum*. Each of these is abundant at certain places in the P.E.I. region. The *Antithamnion* at points such as Cavendish is found in great quantities as an epiphyte on *Chondrus* and *Corallina*. In addition to the distinguishing species found in this region, there are other ways in which the flora is quite distinct. Specimens of both *Ceramium* and *Polysiphonia*, for example, are apt to be quite light in color, and all the *Fuci* except *F. serratus* are very small. Other things could be mentioned, but these are sufficient to bring out the big difference between the marine flora of this region and that of any other part of the Canadian Atlantic coast.

The deficiencies in the marine flora in this locality are at once apparent to anyone accustomed to the ordinary conditions in the northwestern Atlantic. One at once notices the comparative rarity of *Ascophyllum nodosum* and *Alaria esculenta* that are so common everywhere else. *Laminaria longicruris* was not observed though dredging was carried out in likely places, and the *Laminaria* association includes an abundance of *L. phyllitis*, a form that is not found in either of the other regions. *Halosaccion* and *Dumontia* were not observed though they are common on other parts of the coast.

Physical Factors

As might be expected there are exceptional physical conditions accompanying this unusual marine flora. The average surface temperature of the shore water at an exposed part of the coast for the warmest month is from 63 to 64° F., but the maximum is much higher than this. A number of records were made at points along exposed sections of the north shore of P.E.I., where the water is regarded as cold for that island, and it was not unusual for the water to reach 75° F., and at times it was as warm as 78° F. There are places on the south shore where at certain times the water becomes warmer than this.

The tidal movements of this region exhibit features that are strikingly atypical for a marine environment. They are entirely different from the tidal movements either on the Atlantic coast or in the Bay of Fundy. These features, although more marked on the north shore than on the south, are prevalent in the whole P.E.I. region. One characteristic of this peculiar condition is the irregularity of the change in level of the water from high to low tides, at times the difference in height being almost negligible. The maximum rise and fall is between seven and eight feet and the average is

about half this. But in every 24 hr. one of the tides provides very little change of level. This condition becomes extreme on the north shore of P.E.I. where during neap tides there are what are locally called "flat tides." That is, for one of the 12-hr. intervals during the day there is no apparent rise and fall. Sometimes collecting was continued at one place for more than four hours, during which it was not possible to detect any change in the level of the water. As a result of these conditions there are times when there is no regular alternating exposure and submersion of the littoral zone. During these periods the upper part of the zone may be exposed and the lower part submerged for over 12 hr. In marked contrast with this lack of rise and fall is the lateral movement of the water in a general direction parallel to the coast line. This movement takes place continuously, even during the extreme condition of a flat tide. At times the current is quite rapid and is especially noticeable at such places as North Cape, West Point, Borden, and East Point. Due to the regularity of the coast line, however, this lateral movement does not produce any rapid churning of the water such as is seen in the Bay of Fundy. The only exception to this is at East Point, which is the meeting place of two strong currents, flowing at right angles to each other. The tidal conditions described above are typical for the region and are predicted in the tide tables, but additional irregularities may be produced by a strong wind. These irregularities cannot be predicted and may result in making conditions even more unusual. At such times the lateral currents may become very strong and the level of the water kept for a number of hours either higher or lower than the normal. There is some mixing of the water by wave action, for especially on the north shore of P.E.I. there may be quite a surf during or immediately after a storm, but the ocean roll is lacking, hence there is not such a constant beating of the waves as on the Atlantic coast. Often indeed the water may be quite calm. As stated above, the tides do not produce the churning of the water found in the Bay of Fundy. Hence as is expected with these conditions of tide and waves, the water is clear.

The rocks all along the shore are shale or sandstone and are exceedingly soft and friable. There are of course muddy bays, but as a rule the shore is lined by fairly steep cliffs, and the intertidal zone is composed of mud, sand, or flat shelving rocks. These slope very gently, hence in spite of the small rise and fall there is still quite an extensive intertidal zone. The ocean floor near the shore is of a composition similar to the intertidal zone and also slopes very gradually. There is thus an extensive sublittoral area that supports the characteristic and luxuriant sublittoral growth. The extensive flat surfaces of the shelving rocks, with their numerous crevices, form ideal places for the growth of such forms as *Chondrus crispus*, *Corallina officinalis*, *Scytosiphon lomentarius*, *Chordaria flagelliformis*, etc. There is one feature of the rock formation that contributes towards the barrenness of the intertidal zone. The shape and structure of the rocks are such that there are practically no tide pools. This forms a marked contrast to certain parts of the Bay of Fundy and Atlantic coasts. The salinity of the water ranges

from about 2·6 to about 2·9. The salinity of the bottom water near shore is usually from 0.1 to 0.2 degrees higher than the surface water.

A winter condition which results from the various factors just mentioned is the drifting mass of ice formed throughout this region. There is not sufficient action of either tides or waves to prevent its formation. Hence it is formed every winter, and with the lateral movement of the water the ice moves slowly up and down the coast grinding against the exposed parts of the shore as it moves.

Variations Within the Region

There are a number of exceptions to the general rule within this region. In spite of the limited tidal rise and fall, and the uniformly straight coastline, there are a number of large bays that form tidal estuaries, where the water is so very shallow that, when the tide goes out, extensive mudflats covered with *Zostera marina* are left bare. There is usually a central channel through which the water continues to flow. Many of these places occur in this region. The ones visited most frequently during this survey were Bayview near Cavendish, P.E.I., Darnley Basin, P.E.I., and Caribou Harbor near Pictou, N.S. The marine flora of these places includes a number of forms not found elsewhere. These are *Gracilaria confervoides*, *Stilophora rhizodes*, and certain fine species of *Ceramium* and *Polysiphonia*. The most luxuriant growth for the region is found in the vicinity of Souris and East Point. The poorest growth is near the western end of the Strait of Canso in George Bay. There are all gradations between these two. As a rule, *Antithamnion*, the finer filamentous forms of *Ceramium*, and the species of *Laminaria* are more abundant in the slightly colder but more turbulent waters of the north shore of P.E.I. *Phyllophora membranifolia*, *P. brodiaei*, *Stypocaulon scoparium* and *Fucus serratus* are perhaps more abundant in the Northumberland Strait. The waters of the Gulf of St. Lawrence including the north shore of P.E.I. are slightly colder during the summer than the waters of the Northumberland Strait. Also on the north shore of P.E.I. the lateral current is more pronounced. At North Cape, P.E.I., there is a peculiar long narrow reef of round rocks. The rocks are anywhere from one to two feet in diameter. The reef is not more than 20 ft. wide and runs for about half a mile out into the Gulf. At a very low tide it is exposed for 300 or 400 yards and after that for a similar distance it is covered by not more than 3 or 4 ft. of water. This is quite different from anything seen anywhere else, and the flora also is different. It consists chiefly of brown annuals such as *Chorda filum*, *Chordaria flagelliformis*, *Laminaria agardhii* and *L. phyllitis*. A peculiar yellowish green form of *Rhodymenia palmata* is also found here. The most striking exception to the usual conditions in the P.E.I. region is the churning of the water at East Point, P.E.I. This is the one place in this region where the water is mixed violently. The tide flowing along the north shore meets the tide flowing along the eastern end of the island. As these enormous bodies of water are moving quickly at right angles to each other, the scene at East Point at certain times of the day is one of turmoil. At these times, stretching in a straight line

northeast from East Point and away out into the Gulf, is a narrow strip of churning rushing water.

Atlantic Region

General Character of Growth

The part of this area most typically marine is the Atlantic region. It exhibits the fewest extremes in both flora and physical conditions. In most respects it is intermediate between the Bay of Fundy and the P.E.I. regions. There is considerable growth in the intertidal zone, but compared with that of the Bay of Fundy it is patchy. On certain types of shore and on rocks of particular formation the growth is abundant, while other long stretches are practically bare. In most places there is quite an amount of rockweed in the lower portion of the littoral zone, but the growth does not start abruptly as it does is so many places around the Bay of Fundy. Also plants of species such as *Fucus vesiculosus* and *Ascophyllum nodosum* are neither so large as in the Bay of Fundy nor so small as on P.E.I. The average and normal plants of *Ascophyllum nodosum* in the Atlantic region are from 18 to 30 in. long. The sublittoral growth is quite rich, and its appearance is quite different from that in either of the other regions, for at first it appears to consist chiefly of species of *Laminaria* of the long ribbon-like type.

Dominant Forms

The dominant forms in this region for the littoral zone are *Fucus vesiculosus*, *F. evanescens*, *F. platycarpus*, *Ascophyllum nodosum*, and *Porphyra laciniata*. Along with these but not quite so conspicuous though just as prevalent are *Enteromorpha linza*, *E. intestinalis*, *Monostroma fuscum*, *Hormiscia penicilliformis*, and *Bangia fusco-purpurea*. In the tide pools throughout the littoral zone, and on all the rocks at about the low water level and extending out for some distance under the water are extensive mats of *Ilea fascia*, *Scytosiphon lomentarius*, *Chordaria flagelliformis*, and *Dictyosiphon foeniculaceus*. In the sublittoral zone the distinctive forms are *Alaria esculenta*, *Laminaria agardhii*, *L. digitata*, *Chorda filum*, *Desmarestia virdis*, *Halosacion ramentacium*, *Polysiphonia violacea*, *Chondrus crispus*, *Rhodomela subfusca*, *Ceramium rubrum*, etc. Of these sublittoral forms by far the most conspicuous species is *Laminaria agardhii*. At very low tide it can be seen festooned over all protruding rocks and at various places there are beds of this species where the plants are so large and dense that at low tide a 25-ft. sailing boat will be held as fast as though it had run aground. *Laminaria longicruris* that is so typical of the Bay of Fundy region is seldom seen on the Atlantic coast except when washed up on the shore. Actually it is present in fair quantities but grows out of sight in the deep and still water. *Rhodymenia palmata* is present in considerable quantities, but is very inconspicuous because it is usually tucked away in the crevices of the rocks. *Chondrus crispus* forms extensive beds below low water mark, but the plants are laden with mussels and other crustaceans. Thus with the scattered intertidal growth of *Fucus* and the heavy dark brown ribbon-like sublittoral forms, the algal growth of this region has a sombre appearance and is different in every way from either of the other two regions.

Physical Factors

The physical factors of this region are fairly uniform from Cape Sable to Cape North. The average shore surface temperature for an exposed part of the coast for the warmest month is from 57 to 59° F. In the bays and harbors it becomes warmer, but there is no such variation as is found between the head and mouth of the Bay of Fundy. The tides are regular and the maximum difference between high and low tides is a little over six feet. The tidal currents are comparatively inconspicuous. The wave action is the one really extreme condition of this region. The ocean roll and the surf never cease and after a storm the force of the waves is terrific. The rocks along the shore are all hard, being granite, slate, or quartzite. The intertidal zone and the ocean floor near the shore are usually steep, rocky, and rugged. At certain places especially just northeast of Halifax there are shallow bays with mud-flats. At these places the ocean floor near the shore may slope gently for a certain distance. There are many long crescent-shaped sandy beaches. The salinity of the water ranges from about 2.9 to about 3.1%. Ice is not formed along the coast except in the enclosed bays, and unlike the drifting ice of the P.E.I. region, when once it is formed in these bays it remains stationary for the winter.

Variations Within the Region

There are very few exceptions to be mentioned for this region. Mahone Bay is the largest body of semi-enclosed water in the region, and with its numerous islands and reefs, and rather extensive shallow water, it provides conditions not common for the rest of the coast, and a few forms of slightly more southern affinities have been found here. The marine flora of this bay should be studied more carefully. At certain other places the rock formation extends as a series of long reefs for a considerable distance out under the sea. It has been noticed that the seaweed in the wash near these shoal waters is unusually abundant. Whitehead, Tor Bay, Thrumcap, and Lockport are of this nature. Other observations have been made at Lockport that suggest that the flora there may be of special interest. A species of *Sargassum* was collected there and the *Chondrus crispus* found on the rocks in that vicinity is unusually free from attached shellfish. An intensive study of this district might prove profitable. There are without doubt other places in this region where variations from the normal conditions could be found. Where the bottom happens to be suitable for growth there is a very much richer flora than in places where conditions are unfavorable, but comparatively speaking the physical conditions and the marine flora are fairly uniform throughout the whole Atlantic region.

The Bras d'Or Lakes

The Bras d'Or Lakes can be dealt with briefly. The marine flora is like that of a deep tide pool of the upper littoral zone. It includes such species as *Fucus vesiculosus*, *Ascophyllum nodosum*, *Scytosiphon lomentarius*, *Dictyosiphon foeniculaceus*, various species of *Enteromorpha* and *Cladophora* and

bleached forms of *Ceramium*. In the deep parts of the main lake forms like *Phyllophora membranifolia* may be found. The water of these lakes is fairly salty; thus they are regarded as part of the ocean, but unlike the ocean the physical conditions of these lakes might be described as "static." That is the temperature is consistently and uniformly warm during the summer, and the surface freezes over every winter. There is practically no tidal rise and fall, and no currents worth mentioning, except in the narrow channels connecting the lakes with the ocean. The surface is usually calm. Even the waves blown up during a storm are not large and soon die down. The shore may be mud, gravel, or rock. Naturally there is no intertidal zone, but a comparatively fixed waterline like an inland lake. The whole aspect of these Bras d'Or Lakes is the opposite of rugged. From a marine standpoint the outstanding characters are negative, and algologically, they are interesting because they lack a typical marine flora.

Association of Physical Factors with Flora

At the present it would be premature to attempt to arrive at definite conclusions regarding the part played by each physical condition in producing the distinctive flora in each of the regions. But it is profitable to record the cases where there is a consistent association or consistent lack of association between physical factors and a special type of flora.

Temperature of the Water

With the large and consistent difference in surface temperature existing in these three regions, it is inconceivable that some of the differences in the flora are not due to this factor. Setchell (14) has claimed that the maximum summer temperature can be used as a means to divide the algae of the ocean into regions, and he has drawn regional dividing lines for every five degrees difference in maximum summer temperature. However, this temperature factor is so conspicuous that one may be inclined to attribute to it greater importance than it deserves. One cannot help associating the warm waters of the P.E.I. region with the luxuriant growth of *Chondrus crispus*, and the presence of a distinctly southern species such as *Gracilaria confervoides*. On the other hand many of the species found in the P.E.I. region and not found in other parts of the maritime provinces are ones that are reported from the Arctic. *Furcellaria fastigiata*, *Stypocaulon scoparium*, *Chaetopteris plumosa* and *Fucus serratus* are common in the Arctic; yet they are found in the warm waters of the P.E.I. region but not in the cold waters of the Bay of Fundy. Again one is apt to assume that moderately warm water would be conducive to rich growth. If this were the chief factor involved the algae of the Bras d'Or Lakes would flourish. Instead they are sickly and stunted, and the region with the richest growth is the Bay of Fundy where the water is the coldest. Competing with the luxuriance of the cold Bay of Fundy is the sublittoral growth of the P.E.I. region where the water is warmest for the area. Hence it is obvious that too much importance should not be placed on temperature as a limiting factor in the distribution of marine algae.

Tides

The tides are responsible for two sets of conditions to which the algae give a definite physiological response. These are the regular alternating exposure and submersion, and the churning of the water due to tidal currents. Exposure appears to be associated with the healthy growth of certain forms of which *Rhodymenia palmata* is an example. Between tides in the Bay of Fundy the part of the shore where it grows may become quite dry. On the Atlantic the intertidal zone is so narrow that due to the spray from the waves the lower part where the *Rhodymenia* grows is seldom quite dry. The plants of this species found on the Atlantic coast are not in such a healthy condition as those that grow in the Bay of Fundy. At Cape North, P.E.I., and at the mouth of Halifax Harbor in the Atlantic region, *Rhodymenia palmata* was found growing where it was constantly submerged. In both cases the plants were poorly developed, a light yellowish green in color, and badly infested with epiphytes. This and similar evidence with other species would suggest that considerable and regular periods of exposure may be a necessary condition for the healthy growth of certain forms. The absence of healthy intertidal growth in the P.E.I. region may possibly be associated with the irregularities of the tides. However, this is one of the points regarding which it is too early to make a definite statement.

On the other hand there appears to be no doubt regarding the influence of the tides when they cause a mixing and churning of the water. Where clear water is kept stirred and churned right from the surface to the bottom, there the growth is always luxuriant. The whole outer part of the Bay of Fundy region is an example of this. In the P.E.I. region the area around Souris and East Point is the same, while the undisturbed waters of the Bras d'Or Lakes provide a negative example in this respect, suggesting that the scarcity of algal growth in these lakes is due to a certain extent to the complete lack of tidal currents. So many instances such as these were observed and the evidence was so convincing that it is important to stress the constant association between a mixing of the water and a luxuriant growth of marine algae.

Wave Action

Severe wave action is associated with the luxuriant growth of forms of a certain type and the absence of forms of another type. Nearly all the species growing luxuriantly in the surf are linear in shape. There are the ribbon-like and cord-like forms such as *Laminaria agardhii*, *Chorda filum*, *Chordaria flagelliformis*, etc. These apparently thrive in the surging waves and are torn off only during a storm. In among the stipes of these forms and even on the exposed rocky surfaces that are beaten by the waves are delicate filamentous forms such as *Polysiphonia violaceae*, *Antithamnion floccosum*, etc. Just below the low water mark there is usually a band of a very wiry *Halosaccion ramentaceum*. All these species are linear or filamentous in structure. Broad forms like *Laminaria longicruris* and *Rhodymenia palmata* are absent from the exposed rocky surfaces in such a locality. It is probable that they cannot stand the force of the waves, whereas the species with a linear form

provide very little resistance to the surging water. This condition is typical of the whole Atlantic coast where the continuous heavy surf is the only extreme condition of the environment. In contrasting the physical factors and the associated flora just described, with the situation found in the Bay of Fundy, one is justified in associating the lack of continuous severe wave action in the Bay with the abundance of such broad flat forms as *Laminaria longicruris* and *Rhodymenia palmata*.

Nature of Rocks Along the Shore

As far as could be observed the kind of rocks did not have very much effect on growth. Other conditions being favorable, the growth was rich regardless of the type of rock. It was thought that perhaps the algae would have difficulty in becoming established on a smooth surface of a hard rock, so a boulder of smooth hard rock was rolled from above the tide level to a position in fairly turbulent water. Within a month this stone was covered with growth. There is one condition, namely, the friable character of the rocks around P.E.I., which may be a limiting factor in the growth of certain plants. These rocks are so soft that fairly strong holdfasts such as those produced by a *Fucus* will pull away lumps of rock before the stipe or holdfast of the plant will break. This may account for the fact that in the P.E.I. region there are no large plants on any part of the shore subjected directly to the action of the waves. Of course where the shore is soft mud, such as at the head of the Bay of Fundy, there is no algal growth.

The Slope of the Intertidal Zone and the Slope of the Ocean Floor Near the Shore

The relation between the slope of the zone of growth and the richness of the flora appears to be obvious. Most seaweeds do not flourish on a perpendicular surface, and practically all the species grow better if the surface is somewhat sloping. The most important consideration in this respect is the area of the zone where it is possible for algae to grow. Although marine algae may grow at considerable depths, the largest part of the sublittoral growth in the area considered is found within about 12 ft. of the surface of the water at low tide. The zone of growth is thus from high water mark to about 12 ft. below low water mark. Where the surface is perpendicular the zone is very narrow and the area of growth is small. Where the surface is sloping the area is greatly increased and in addition it provides a more favorable place of attachment for the majority of forms. So naturally the most abundant growth occurs where the intertidal zone and the ocean floor near the shore slope gently. This gently sloping condition is characteristic of the whole of the Bay of Fundy and the P.E.I. regions. In the Atlantic region there are a number of places, such as Lockport, where this condition prevails, and as already mentioned it is at these places one finds the most abundant growth.

Salinity

So far as the three main regions are concerned, there is no reasonable suggestion of any association between the salinity of the water and the distinctive character of the flora of each region. There is no doubt that a very low

salinity inhibits marine algal growth. There is a splendid illustration of this at St. George, New Brunswick. One reaches St. George by an inlet that is about four miles long and from a quarter of a mile to a hundred yards wide. The salinity of the water grades from normal at the mouth to pure fresh water near the falls at the head. The plants of *Fucus vesiculosus* are large and normal at the mouth of the bay. They continue to grow right up to the fresh water, but become smaller and smaller, till those at the upper limits are but little protuberances on the rocks. There are without doubt other conditions involved, but the salinity appears to be the chief factor. Evidence like this could be multiplied and would suggest that salinity has a decided local influence on algal growth. However it is difficult to attribute the diverse conditions of growth in the three regions of this area to differences in salinity. The difference of 0.2% between the average salinities of the Bay of Fundy and Atlantic regions seems insufficient to cause any great difference in growth, for there is a greater variation than this within each region. The P.E.I. region has a lower salinity, but the forms that flourish there are species that in other parts of the world are typical of places where the salinity is normal. The slight difference in the salinity of the surface water and the bottom water near the shore seems hardly enough to cause the big difference between the scanty littoral and the rich sublittoral growth. A more intensive and comparative study of local conditions in limited and contrasting areas is necessary before one could draw any conclusions.

Ice Action

Due to the conditions already described in the paragraphs for each region, ice appears to have very little influence on the growth of the algae in either the Bay of Fundy or the Atlantic. But the exposed rocks in the P.E.I. region provide evidence indicating that there the ice is a very important factor. On a point of land, the rock surface facing the open bay is exposed to the action of the laterally drifting ice. Any crevice in the rock provides a surface not subjected to the moving ice, yet in these crevices the wave action is more severe. Studying the rocks all along the shore from this standpoint, the surfaces that are scraped by the moving ice are bare, but the surfaces that are protected from the ice action, even though they might be subjected to many other destructive agencies, are more or less covered with some form of growth. This evidence suggests that the lateral movement of the large mass of floating ice may be one of the factors responsible for the barren intertidal zone in the P.E.I. region.

It is important to restate the object of this summary. Its purpose is to bring out the great differences in the marine flora of the three main regions in this area, and to place on record the ways in which the differences in marine flora appear to be associated with physical conditions. These observations were made during a survey of the marine algae of the Atlantic maritime provinces of Canada. It is not intended to make any broad deductions from this evidence, for it is felt that a more intensive study of certain regions, and some experimental work are necessary before this could be done, but these three regions provide such striking contrasts that the area as a whole is an ideal situation for ecological investigation.

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GELASINOSPORA, A NEW GENUS OF PYRENOMYCETES WITH PITTED SPORES[1]

By Eleanor Silver Dowding

Abstract

Gelasinospora is a genus closely related to *Sordaria*, characterized by the foveolate sculpturing of the spore wall. At present it contains two species, as follows:—

I. *Gelasinospora tetrasperma*, a coprophilous fungus which has been cultivated from spores collected in Manitoba and in Ontario.

The species is described, together with illustrations of the chief characters, such as the four-spored condition of the ascus and the thickened ring bordering its apical perforation.

Each normal-sized spore gives rise to a homothallic mycelium. The normal spore contains four nuclei. Asci very occasionally produce dwarf spores. Each dwarf spore gives rise to a mycelium which produces archicarps, but no perithecia. The mycelia from dwarf spores fall into two groups, (+) and (−), in regard to their sexual behavior. When (+) and (−) mycelia are paired, perithecia are produced. Sometimes asci contain giant spores. The giant spores usually produce homothallic mycelia and the spores usually contain six nuclei.

II. *Gelasinospora cerealis*, isolated from the crown of wheat and oats in Manitoba.

The species is described, together with illustrations of the chief characters, such as the eight-spored condition of the ascus and the two radial thickenings at its apical perforation.

Each spore gives rise to a homothallic mycelium. The spores are binucleate.

I. Diagnosis of Genus and Species

Two previously undescribed species of Pyrenomycetes have recently come to the attention of the writer, both species being characterized by the presence of strikingly pitted sculpturing on the spore walls. On account of the spore markings, the genus has been named *Gelasinospora*, from "gelasinos" (γελασινος), a dimple. *Gelasinospora* is closely related to two other genera, *Neurospora* (the red bread-mold fungi), and *Sordaria*.

Gelasinospora gen. nov.: Perithecia sparsa vel conferta, conica vel pyriformia, fusca vel atra; rostro conoideo, brevi; asci stipitati, aparaphysati, apice perforato; sporidia hyalina, demum fusca, denique atro-opaca; episporio eleganter et regulariter foveolato; macroconidia et microconidia absentia. Species typica, *G. tetrasperma*.

The spores of *G. tetrasperma* and *G. cerealis* are flattened slightly (Text-figs. 3*a* and 9). Foveolate markings are most easily observed in the young spores. When examining the mature spores, it is necessary to use a strong light on account of their black color. It is even more satisfactory to crush the spores between a slide and cover slip, when the pits show very distinctly on the fragments of the walls (Text-fig. 4, *a* and *b*; Plate III, Fig. 8).

Gelasinospora tetrasperma spec. nov.: Perithecia sparsa, erumpentia, atra, opaca, pyriformia, membranacea, 0.3 × 0.6 mm., basi hyphis radiantibus cincta; rostro glabro, conoideo; asci plerumque tetraspori, interdum 1-, 2-, vel 3- spori, cum giganteis sporis, raro 5-spori cum nanis sporis, 8 × 230μ, aparaphysati, permanentes, cylindracei, apice asci truncato, perforato, ore circumvento crasso annulo; ascospori plerumque 13.2-16.0μ × 20-28μ,

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interdum 15.0-19.8μ × 38.0-42.9μ vel 10.0-13.2μ × 16.5-18.0μ, visi a dorso ellipsoidei vel ovoidei, visi a latere plani vel fabiformi, hyalini primo, viridi-atri serius, foveolati; species homothallica.

On ptarmigan and rabbit dung. Manitoba and Ontario.

Distinctive characters: four-spored asci with thickened rim about apical perforation.

Gelasinospora cerealis spec. nov.: Perithecia sparsa, erumpentia, fusca, translucida, subglobosa, membranacea, 0.3-0.4 mm. × 0.6-0.7 mm., basi sparsis hyphis cincta, rostro glabro, cylindrico; asci octospori, 29.7-33.0μ × 214.5-260.0μ, aparaphysati, permanentes, cylindracei; apice asci truncato, perforato, incrassato radiatim in duobus locis; ascospori 23.1-25.0μ × 26.4-32.0μ, visi a dorso late ellipsoidei vel sub globosi, visi a latere plani vel fabiformi, interdum apiculati, hyalini primo, atri serius, foveolati; species homothallica.

Isolated from the crown of wheat and oats. Manitoba.

Distinctive characters: eight-spored asci with two radial thickenings near the perforation; subglobose spores, occasionally apiculate at one end.

Cultures of *G. tetrasperma* and *G. cerealis* have been deposited with the Centraal Bureau voor Schimmelcultures, at Baarn.

II. Material and Methods

(1) *Gelasinospora tetrasperma*

In 1932 this fungus was first obtained from ptarmigan droppings collected by Mr. Wm. Güssow, in Manitoba about 30 miles north of Fort Churchill on Hudson Bay. The following winter, in Ottawa, the dried dung was moistened, and in less than a week four or five perithecia developed which were the source of the cultures used. Spores from the perithecia were transferred to culture media and the fungus has been kept in cultivation at Ottawa for the last three months.

The writer described the new species to Dr. R. F. Cain of the University of Toronto, who is engaged in making a special study of the Sordariaceae of Ontario (1). He stated that Mr. J. Savage in 1931 collected rabbit dung near Thunder Bay on the north shore of Lake Superior in Ontario, and when this material was moistened in the laboratory a similar Pyrenomycete with pitted spores developed upon it. The fungus from Ontario is not in culture at present, but permanent slides of the perithecia and spores show that it is apparently identical with the fungus collected at Hudson Bay. We may therefore assume that *G. tetrasperma* occurs in Ontario as well as in Manitoba.*

* *As this paper goes to press, the writer has received from England cultures of "Sordaria fimicola, (four-spored form)" from Miss Page. Miss Page (14), has shown that her fungus exhibits the same sexual and nuclear condition that the writer has found in G. tetrasperma. Miss Page's species is foveolate-spored, and is identical in appearance in every other way with G. tetrasperma. In both fungi there are normal-sized bisexual spores, and, occasionally, dwarf spores which produce heterothallic mycelia. Four monosporous mycelia of G. tetrasperma, two of (+) and two of (−) reaction, all derived from dwarf spores, were each paired with a (+) and with a (−) mycelium of dwarf-spore origin from the four-spored S. fimicola. No perithecia were formed on any of the eight paired mycelia. The writer considers Miss Page's S. fimicola to be G. tetrasperma even though it is sexually incompatible with the Canadian G. tetrasperma. The English cultures were cultivated from soil which was collected by Mrs. H. S. Williamson in 1930 at Oxshott.*

(2) *Gelasinospora cerealis*

This species has been collected so far only from Manitoba. It was isolated by Dr. J. E. Machacek in 1932, from the diseased crown of oats growing at Souris, Manitoba, and also found in the diseased crown of Durum wheat at Deloraine. Dr. G. R. Bisby, of the University of Manitoba, had examined with much interest the cultures of *G. tetrasperma* submitted him by the writer. He sent in return Dr. Machacek's culture, which resembled *G. tetrasperma* so closely that he considered that it might possibly be included in the same genus. The fungus was subsequently named *G. cerealis*.

G. cerealis was obtained by Dr. Machacek from the diseased cereal plants by stripping away the culms and roots from the underground part above the seed, and after washing and surface-sterilizing these parts, they were plated out on agar that was still warm.

G. cerealis may be one of the organisms causing foot rot, or it may be a soil-inhabiting fungus occurring occasionally as an accidental saprophyte on cereal crowns.

(3) *Spore Deposits*

To obtain a spore-deposit of *G. tetrasperma* or *G. cerealis*, a glass plate is suspended an inch or two above the ripe perithecium for about an hour, so that spores discharged from the perithecium form a deposit against the under surface of the glass. When the spores of either species are discharged from the ascus they do not cling together as in *Pleurage anserina* (5), but become separated from one another in the air, so that in a spore deposit it is impossible to recognize sister spores (Text-fig. 6).

In a spore deposit of *G. cerealis* there is some variation in spore size, but in *G. tetrasperma* the variation is extreme. Most of the spores of *G. tetrasperma* are of constant size (about 25μ long), but there is occasionally, once among about 200 spores, a giant spore about 40μ long, and still more rarely, once among about 2,000 spores, a dwarf spore only about 17μ long (Text-fig. 6).

(4) *Culture Methods*

In order to obtain monosporous mycelia, spores were removed one by one from a spore deposit by the aid of a needle (8) and transferred singly to sterilized tubes of culture medium. The mycelia were found to grow readily on malt agar, prune agar, potato-dextrose agar, cornmeal agar and horse-dung agar. Throughout the investigation malt agar was used for the culture medium.

Dodge (2) has shown that spores of many coprophilous Ascomycetes germinate more readily after they are heated. The writer had sent cultures of *G. tetrasperma* to Dr. Dodge, and relative to these cultures he writes from New York "not a single ascospore germinated after twelve hours or so." (He had sown spores of *G. tetrasperma* on cornmeal agar.) "I then submitted the

spores to a temperature of about sixty degrees for three-quarters of an hour, and much to my surprise obtained a high percentage of germination."

Spores shaken up in sterile water were poured over two malt agar plates. One plate was left unheated and the other was heated in an oven for half an hour, until a temperature of 52° C. was reached, and slowly allowed to cool. It was found that about three times as many spores germinated in the heated as in the unheated plate.

The experiments about to be recorded on the sexuality of the spores of *G. tetrasperma* and *G. cerealis* were carried out before the expedient of heating the spores had been tried. The unheated spores gave sufficiently high germination for the purpose, for out of 100 spores sown separately on agar slants without being heated, 26 germinated.

When a Petri dish is inoculated with the mycelium of *G. tetrasperma* or *G. cerealis*, hyphae grow out rapidly from the inoculum at a rate of about 2 mm. per hour, so that after 24 hr. the mycelium has grown over the surface of the agar to the periphery of the dish. It then forms aerial mycelium at the sides of the dish. In *G. tetrasperma* the aerial mycelium is very abundant and is flesh-pink in color. In *G. cerealis* it is not so abundant and it is white except after being collected together with needle or forceps, when it appears pale pink. In about three days minute archicarps appear over the surface of the agar and on the aerial mycelium on the glass, and in about five days the archicarps have developed into mature perithecia. The two species of *Gelasinospora* thus complete their life history in less than a week.

III. The Genus Gelasinospora

(1) *Comparison with Sordaria*

Gelasinospora resembles *Sordaria* very closely. The perithecia of *S. fimicola* Ces. and De Not., which may be considered the type species of *Sordaria* (Plate I, Figs. 1 and 3), and the perithecia of the two species of *Gelasinospora* (Plate II, Fig. 1; Plate III, Fig. 1) are all superficial, smooth, short-beaked, dark colored, membranaceous, and pyriform. The asci of both genera are pored (Plate II, Fig. 7; Text-fig. 9). The eight-spored *G. cerealis*, and the eight-spored species of *Sordaria*, as far as they have been investigated, are homothallic (9). The two genera differ in that the spores of *Sordaria* are smooth and possess a mucilaginous sheath, while those of *Gelasinospora* are pitted, and possess no sheath (Plate I, Fig. 3).

Spores of the two species of *Gelasinospora* have been examined at all ages within the ascus, and also after discharge. Discharged spores have been examined in various media, water, glycerol, lactic acid, iodine, and India ink, and in air. Of the spores examined in air, some were from old spore deposits and some were recently discharged and still wet. For illumination an open diaphragm, a partly closed diaphragm, and a dark-field condenser were each tried in turn. The spores of *S. fimicola*, which are provided with a distinct sheath (7, 13) (Plate I, Fig. 3), were used for comparison, and from these

examinations nothing could be seen on the spores of either of the species of *Gelasinospora* that could be described with certainty as a mucilaginous sheath.

After the spores of *S. fimicola* are stained in gentian violet, the mucilaginous sheath takes on a deep violet color. The spores of *G. tetrasperma* and *G. cerealis* when similarly treated show no such violet sheath. When spores are examined in air or in liquid, with the light cut down to a narrow beam, a shining band about 1μ wide appears about the spore. This band was finally interpreted as being due to refraction.

The spores of *G. tetrasperma* and *G. cerealis* possess some protoplasmic or mucilaginous material which clings to them after their discharge. It appears as an occasional thin fringe of granular material, stained by gentian violet. This material appears to cement the spores to any object to which they adhere, because if spores are removed from a spore deposit by a needle, they leave a circular imprint of some refractive substance on the glass (Plate II, Fig. 10). It is probable that any species of spore which is discharged through the pore of an ascus is similarly lubricated; but such a scanty, indistinguishable covering could not be taken for a mucilaginous sheath in the sense that this term is used by systematists to define the genus *Sordaria*.

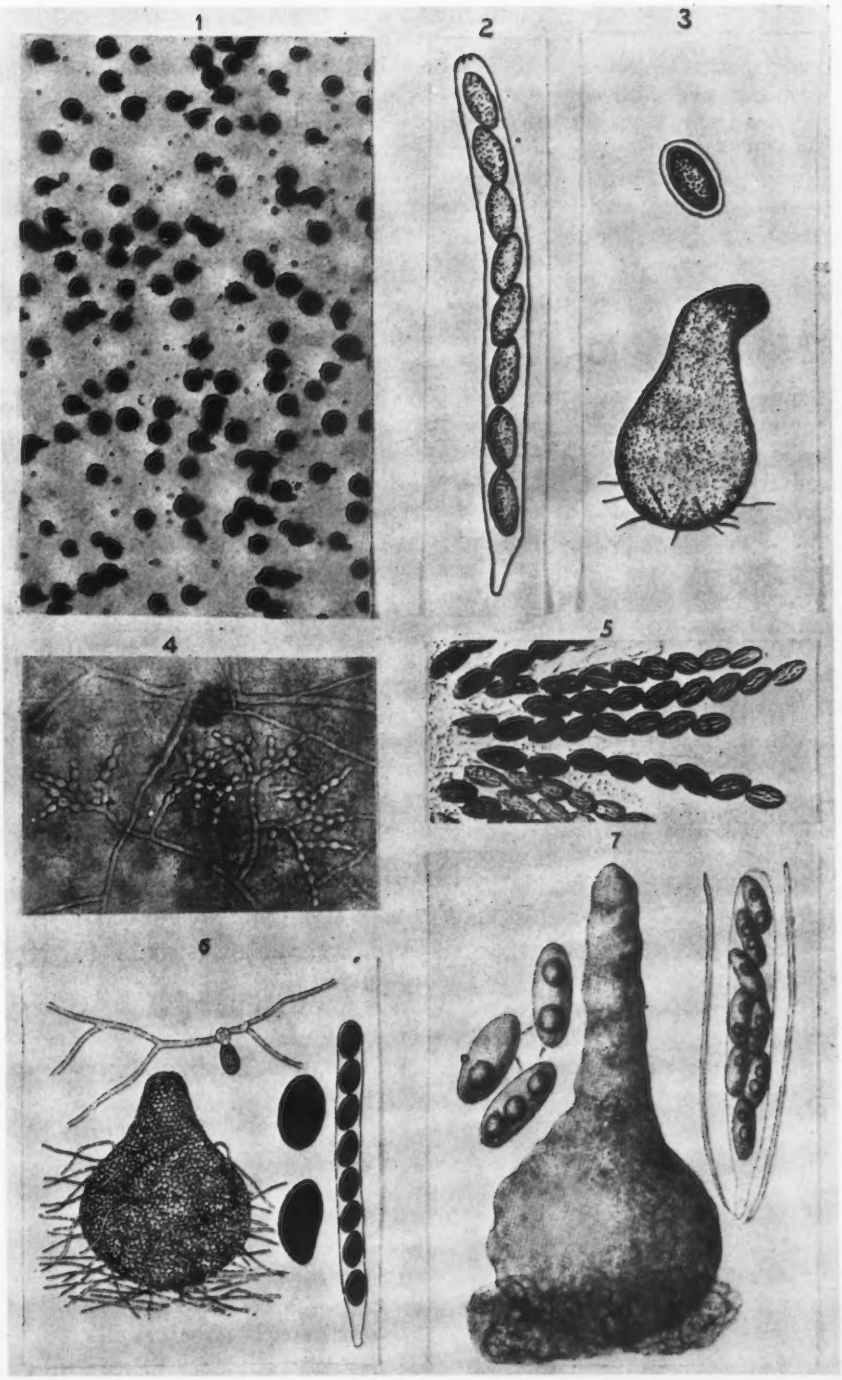
(2) *Comparison with Neurospora*

Members of the genus *Neurospora* Shear and Dodge possess superficial, black perithecia similar to those of *Gelasinospora*. They possess asci with a single pore. Hyphae occupy the central cavity of the young perithecium, at the time the first asci are being developed, but in the mature perithecium there are no paraphyses. *Neurospora* can be distinguished from *Gelasinospora* by the longitudinal nerve-like markings on the spore wall (Plate I, Fig. 5), and by the possession of macroconidia (Plate I, Fig. 4) and microconidia. It differs from *Gelasinospora* also in that the eight-spored species (*N. crassa* Shear and Dodge, and *N. sitophila* Shear and Dodge) are heterothallic (3, 17), while the eight-spored *G. cerealis* is homothallic.

The two four-spored species, *G. tetrasperma* and *N. tetrasperma* Shear and Dodge, are similar in that both normally produce bisexual spores, but occasionally produce dwarf spores which produce heterothallic mycelia. Dr. B. O. Dodge in 1932 (4) had obtained a fertile interspecific hybrid in the genus *Neurospora* and he suggested that the writer attempt to produce an intergeneric hybrid by mating the dwarf spores of *G. tetrasperma* and *N. tetrasperma*. Acting upon this suggestion, seven monosporous mycelia of *N. tetrasperma* and five monosporous mycelia of *G. tetrasperma* were obtained from dwarf

EXPLANATION OF PLATE I

FIG. 1. *Sordaria fimicola—a malt agar culture producing perithecia. Photograph by Güssow.* × *10.* FIG. 2. *S. fimicola—pored ascus containing eight spores. After Griffiths.* × *440.* FIG. 3. *S. fimicola—perithecium, and spore with mucilaginous sheath. After Griffiths. Perithecium,* × *65; spore,* × *575.* FIG. 4. *Neurospora sitophila Shear and Dodge—macroconidia. After Shear and Dodge.* × *185.* FIG. 5. *Neurospora sitophila—asci, each containing eight spores with nerve-like markings. After Dodge.* × *300.* FIG. 6. *Anthostomella destruens (Melanospora destruens) showing perithecium, ascus, and spores. After Shear.* FIG. 7. *Ceratostoma avocetta (C. and E.) Sacc.—showing perithecium, ascus with paraphyses, and spores. The perithecium of this species is often buried in the wood. After Clements and Shear. Perithecium,* × *80.*



Fungi allied to Ge'asinospora.

spores. The 12 mycelia were paired in all possible combinations. No perithecia were produced when mycelia of the two species were grown together, even after two months, although perithecia were produced when mycelia were mated which were of the same species but of different sexual groups. The attempt to obtain a hybrid between *N. tetrasperma* and *G. tetrasperma* was therefore unsuccessful. Furthermore, the paired mycelia of different genera exhibited no reaction whatever which could be interpreted as a sexual response.

(3) *Comparison with Anthostomella and Ceratostoma*

Anthostomella is distinguished from *Gelasinospora* by the persistently submerged habit of the perithecia, and the possession of paraphyses.

Anthostomella destruens Shear (15, 16), was first isolated in 1907 from the pulp of a diseased cranberry grown in New Jersey. Shear himself does not consider *A. destruens* to be typical of *Anthostomella* because it has no paraphyses, and to judge from his figures (Plate 1, Fig. 6), the perithecia are superficial, not submerged. It has recently been included in *Melanospora*, but it is doubtful whether the new classification is more satisfactory. *M. chionea* (Fr.) Cda., which has been considered the type species of *Melanospora*, has a grey perithecium with a long slender beak, fimbriate at the apex, in marked distinction from the dark-colored, short-beaked perithecium of *A. destruens*.

The writer examined preserved specimens of perithecia and spores of *A. destruens*, kindly sent by Dr. Shear. To add to his description (16), the perithecia are superficial, and clothed in a web of hyphae. They are black and opaque except in a strong light when they appear brown and translucent except for the beak. The spores in one view appear flattened.

Mason (10) examined American and English cultures of *A. destruens* for microconidia. He states, "In spite of repeated efforts, phialides have been seen neither in the isolation maintained at the Lister Institute nor in the present culture," (isolated from a rotten apple at London).

In all the characters mentioned by Shear (16) and in those above described, *A. destruens* agrees with *Gelasinospora*.

A. destruens differs from *Gelasinospora* only in the possession of smooth-walled spores. After examining large numbers of the smooth spores of *A. destruens*, the writer discovered one spore which was distinctly pitted.

From these observations it is concluded that of the Pyrenomycetes allied to *Gelasinospora*, *A. destruens* is the most closely related species known.

The genus *Ceratostoma* is similar to *Gelasinospora* in the superficial habit of the perithecium, but is distinguished by its long beak (Plate I, Fig. 7). Dr. Shear drew the writer's attention to a fungus described by Nichols (12) as *C. brevirostre*, but which was later considered not to be Fries species. From Miss Nichols' description of the rapid growth of the fungus, the abundance of perithecia, and the absence of conidia, one might place her species very near to, if not within, the genus *Gelasinospora*.

(4) *A Previously Described Pyrenomycete with Pitted Spores*

In 1897, Mouton (11) described and figured the spores of a Pyrenomycete collected only once from Beaufays near Liège, Belgium, on charred sawdust. To the knowledge of the writer, it is the only recorded Pyrenomycete with pitted spores and they are said to be "elegantly, and regularly foveolate." Because of its coriaceous perithecium the fungus was placed in the genus *Rosellinia*, and it was named *R. calospora* on account of its beautiful spores. If this species is rediscovered it must then be decided whether or not it should become a member of the genus *Gelasinospora*.

IV. Gelasinospora tetrasperma

(1) *Description of Species*

The perithecia of *G. tetrasperma* are black, and even under the strongest light, completely opaque. They are shown in Plate II, Figs. 1, 3, 4 and 11. The hyphae which clothe their base are brownish (Plate II, Fig. 1).

Photographs of normal asci are shown in Plate II, Figs. 2 and 5. The stipes, which are not illustrated, are moderately long and slender. Reference to Text-fig. 7 will show the different types of asci that have been observed. There are figured: A, a four-spored ascus with normal spores; B, asci with fewer than four spores, containing normal and giant spores; C, asci with five spores, containing normal and dwarf spores; D, asci with four spores, containing normal, giant and dwarf spores. The ascus pores bordered with mucilaginous bands are sketched in Text-fig. 5, *a*, *b*, and *c*, and a section of a perithecium in which the bands about the perforations have been stained in safranin is photographed in Plate II, Fig. 7. The gelatinous band also stains brilliantly in cotton-blue dissolved in lactic acid. Faull (6) describes and illustrates a similar gelatinous rim about the ascus perforation of *Neurospora crassa*.

The spores, although black in ordinary illumination, are distinctly green in a strong light. Their shape is shown in Text-figs. 3, 5 and 6 and in Plate

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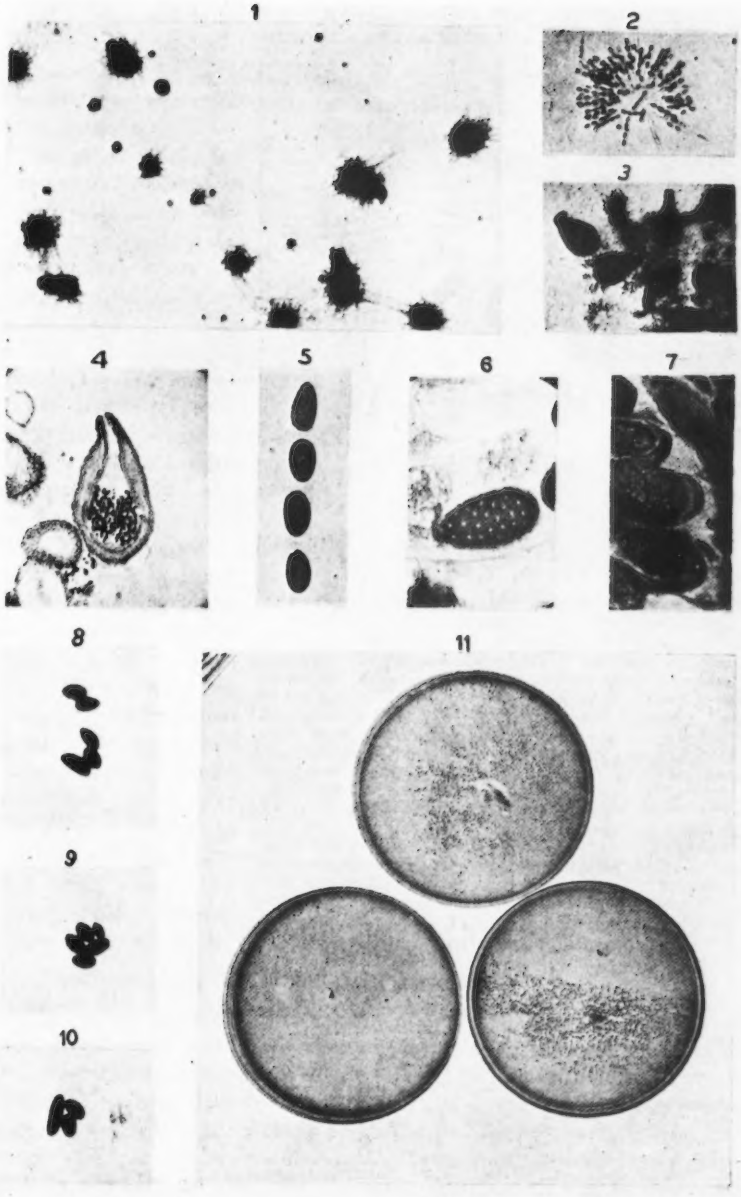
EXPLANATION OF PLATE II

All figures are those of Gelasinospora tetrasperma

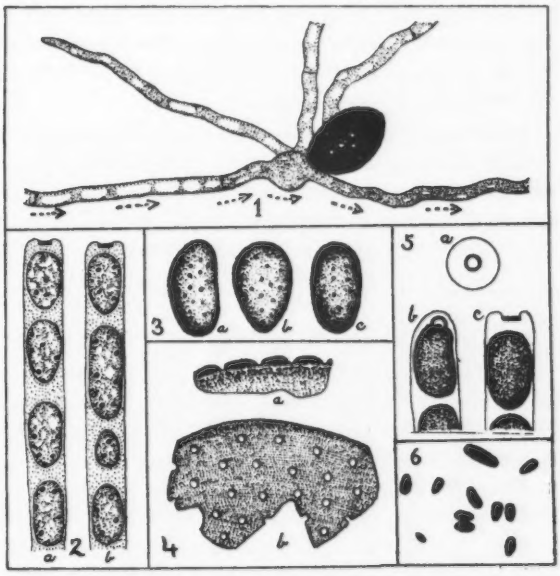
FIG. 1. *A malt agar culture, producing perithecia. The perithecia are surrounded at their base with aerial hyphae.* × *15.* FIG. 2. *A group of asci in water, obtained by crushing a perithecium between a slide and coverglass. At the upper left is an ascus, containing two normal spores and one giant spore. There are no paraphyses.* × *40.* FIG. 3. *Crushed perithecia.* × *15.* FIG. 4. *Section of a perithecium, stained, showing spores and periphyses.* × *40.* FIG. 5. *Four young spores in an ascus. Pits are clearly shown on the spore walls.* × *300.* FIG. 6. *A ripe spore within the perithecium, showing pitting.* × *625.* FIG. 7. *Section of a perithecium, stained, showing the tips of five asci. The three uppermost apices show pores bordered by thickened bands which have stained deeply.* × *625.* FIG. 8. *A deposit of five normal-sized spores.* × *180.* FIG. 9. *A deposit of four normal, and one dwarf spore.* × *180.* FIG. 10. *A deposit of two normal, and one giant spore. To the right is a gelatinous impression left by a group of spores which have been rubbed off the glass.* × *180.* FIG. 11. *Above, a plate of malt agar which has been inoculated with a single normal spore. The mycelium is a week old and has produced perithecia. Left, a similar culture of a mycelium from a single dwarf spore. The mycelium is a month old, and is sterile. Right, a plate inoculated with two mycelia derived from two dwarf spores. Perithecia were formed where the two mycelia met, and now, when the culture is two weeks old, they have spread over one-half of the plate.* × ½.



Gelasinospora tetrasperma spec. nov.

II, Figs. 5, 8, 9 and 10. Although some are elliptic, others are strongly ovate. The spore pits are photographed in Plate II, Figs. 5 and 6, and sketched in Text-fig. 4, *a* and *b*. The spores germinate from one end only, where a primary vesicle is first produced (Text-fig. 1). The mycelium produces no macroconidia.

As phialospores are frequently found in fungi related to *Gelasinospora* (10), a careful search was made for microconidia in *G. tetrasperma*. The fungus was grown on the following media: malt agar, potato-dextrose agar, prune agar, corn-meal agar, horse-dung agar, and on both filter-paper and soil impregnated with horse-dung decoction. The mycelium was examined microscopically on the agar plate on which it was growing, and mounted in water between a slide and cover slip. Sterile water was poured over the aerial mycelium of cultures and the water was then examined under the microscope. No microconidia were ever discovered from these examinations.



TEXT-FIGS. 1-6. *Gelasinospora tetrasperma. Camera lucida drawings of spores. Magnification:* FIG. 4, *1,350;* FIG. 6, *60; all other figures, 300.* FIG. 1. *Germinating spore. The spore has produced a vesicle at one end which has given rise to five hyphae. Protoplasm and vacuoles are moving in the direction of the arrows.* FIG. 2. *Young asci stained in safranin and light-green, to show the nuclei in the spores: a, an ascus containing normal spores, each with four nuclei; b, an ascus containing abnormal spores. The giant spore possesses six nuclei, the dwarf spore, two.* FIG. 3. *Mature spores: a, spore in lateral view; b, ovoid spore in face view; c, ellipsoid spore in face view.* FIG. 4. *Fragments of the wall of a crushed spore, showing pits: a, pits in profile; b, pits in face view.* FIG. 5. *Apices of asci, showing ascus perforations with thickened margins: a and b, face views; c, side view.* FIG. 6. *Spores from a spore-deposit. At the top is a giant spore, at the lower left a dwarf.*

(2) *The Sexuality of the Normal and Abnormal Spores*

The results obtained from experiments on the sexuality of the spores of *G. tetrasperma* agree with those reported from similar work on other four-spored Ascomycetes with abnormal spores. In 1927, Shear and Dodge (17) and Dodge (3) showed that the normal and giant spores of *N. tetrasperma* produce mycelia which are all capable of giving rise to perithecia, while the dwarf spores produce mycelia which remain sterile unless appropriately mated. In 1931, the writer (5) obtained the same results with *Pleurage anserina*. In 1933, Page (14) working with "*Sordaria fimicola* (four-spored form)" found that the normal and abnormal-sized spores of this species behaved similarly.

To determine the sexuality of the normal-sized spores of *G. tetrasperma*, 26 normal spores were sown separately on slants of malt agar and induced to germinate. Every one of the 26 monosporous mycelia produced perithecia in less than a week. Plate II, Fig. 11, top, shows a monosporous culture derived from a normal spore. The culture was a week old and was producing perithecia. From 26 such cultures it is concluded that the normal-sized spores are bisexual.

After sowing a number of dwarf spores separately on agar slants, five monosporous mycelia of dwarf-spore origin were obtained. The five mycelia were periodically transferred to fresh medium and kept for three months. At the end of that time every one of them remained sterile. After the first week there appeared, upon all the cultures, archicarps barely visible to the naked eye. These bodies eventually became greyish in color but never developed into perithecia. Plate II, Fig. 11, *left*, shows a monosporous culture a month old, derived from a dwarf spore. The mycelium has produced no perithecia.

The five mycelia, Nos. 1, 2, 3, 4, and 5, were then mated to one another in all possible ways by planting pairs of inocula side by side on malt agar slants. From the 15 matings it was found that mycelia Nos. 1 and 2 remained sterile when mated with each other, that mycelia Nos. 3, 4, and 5 were sterile when mated with one another, but that mycelia Nos. 1 or 2 when mated with mycelia Nos. 3, 4 or 5 produced perithecia in less than a week.

Plate II, Fig. 11, *right*, shows a Petri dish in which a pairing has been made between the two mycelia, 1 and 3. When the two mycelia met, perithecia first appeared along the line of contact. The perithecia-producing band subsequently widened and spread over one half of the dish. It would appear from the uneven distribution of the perithecia on the agar in the photograph, that one mycelium has invaded the territory of the other and there initiated the production of perithecia. From 15 similar paired cultures, it is concluded that the five mycelia derived from dwarf spores fall into two groups on the basis of their sexual reactions. Mycelia Nos. 1 and 2 belong to one group, and Nos. 3, 4 and 5 to the other group. The mycelia are all morphologically alike but are heterothallic in the sense that it is necessary to have the cooperation of two mycelia belonging to different physiological groups to produce perithecia.

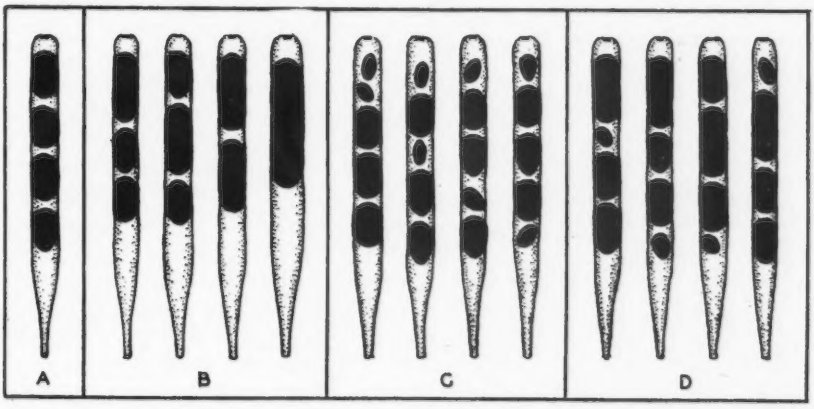
Ten monosporous mycelia derived from giant spores were then grown on agar slants. In less than a week nine of the ten mycelia had produced perithecia. We may, therefore, assume that giant spores of *G. tetrasperma* are usually bisexual.

The one sterile mycelium derived from a giant spore was kept three months and it still remained sterile. The mycelium was then mated with each of the five mycelia derived from dwarf spores. It produced perithecia when it was mated with "dwarf mycelia" of one sex, but remained sterile with mycelia of the opposite sex. The one exceptional giant spore must, therefore, have given rise to a mycelium similar to that from a dwarf spore.

(3) *The Number of Nuclei in the Normal and Abnormal Spores*

In order to obtain material with which to make permanent sections of perithecia, agar plates were inoculated with mycelia of *G. tetrasperma*. Eight or nine days after inoculation blocks of agar with perithecia upon their surface were cut out of the plate, immersed for one minute in Carnoy's fluid, and transferred to Flemming's fluid (medium strength), where they were allowed to remain for 24 hr. The material was then washed in tepid water for two and one-half hours, dehydrated, imbedded in paraffin, cut by microtome, and stained with safranin and light-green.

After this treatment, in the very young spores the nuclei could be distinguished by their red color. In the older spores the pigmented wall made it impossible to observe the protoplasmic contents.

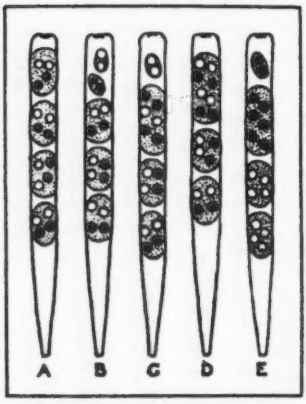


TEXT-FIG. 7. *Gelasinospora tetrasperma. Diagram of the different types of asci actually observed: A, normal ascus containing four spores; B, asci containing less than four spores; C, asci containing five spores; D, asci containing four spores, some of which are abnormal in size.*

It was found that *normal* spores of *G. tetrasperma* contain *four* nuclei (Text-fig. 2, *a*). After considerable search, five or six sufficiently young dwarf spores were discovered. The *dwarf* spores each contained *two* nuclei. About 12 young *giant* spores were found. Each contained *six* nuclei. It is possible that there are also giant spores which contain 8 or even 16 nuclei. Such giant spores are shown in Text-fig. 7, B.

It happened that in one section there was an abnormal four-spored ascus which contained one dwarf, one giant and two normal spores. The dwarf spore contained two nuclei, the giant six, one normal spore four, while in the other normal spore two nuclei could be seen distinctly and two less distinctly (Text-fig. 2, *b*). It is likely that young abnormal asci, as well as young normal asci, always contain 16 nuclei, because we have no reason to suppose that an abnormal delimitation of spores is ever accompanied by an abnormal number of cell divisions.

The results of the experiments upon the sexuality of the normal- and abnormal-sized spores, and the corresponding variation in the number of nuclei within the spore, go to show that the nuclei within a mature ascus may be of two kinds, which we might designate as (+) and (−). Spores which produce fertile mycelia may contain *both* (+) and (−) nuclei; spores which produce sterile mycelia may contain *either* (+) *or* (−) nuclei. Text-fig. 8 shows five of the many possible arrangements of (+) and (−) nuclei in different asci.



TEXT-FIG. 8. *Gelasinospora tetrasperma. Diagram representing five of the possible ways in which nuclei might be arranged in the ascus. Nuclei of one "sex" are shown white, of the other black: A, normal ascus with four spores all capable of producing fertile mycelia; B, ascus containing two dwarf spores, which would produce mycelia that would remain sterile unless mated together; C, ascus with a dwarf spore, which would produce a sterile mycelium, and a giant spore with four (+) and two (−) nuclei; D, ascus with a giant spore with four (+) and four (−) nuclei; E, ascus with a dwarf and a giant spore, the mycelia of which would both be sterile.*

V. Gelasinospora cerealis

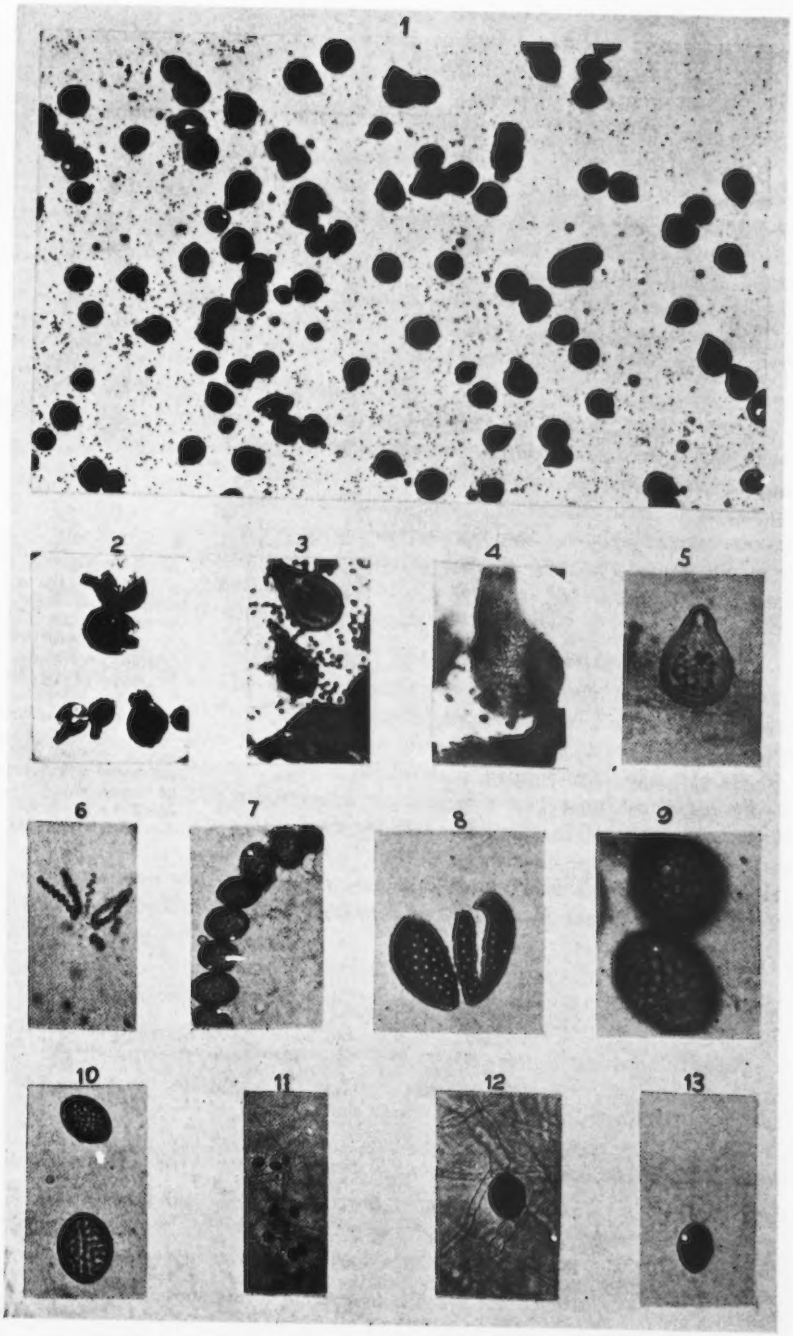
(1) *Description of Species*

The perithecia of *G. cerealis* usually appear black (Plate III, Figs. 1 and 2), but when examined with a strong light they are brown and faintly translucent (Plate III, Figs. 3 and 4). They are almost spherical in contrast with the more pyriform perithecia of *G. tetrasperma*. The perithecia contain periphyses as shown in Plate III, Fig. 5, but no paraphyses. Plate III, Figs. 6 and 7, and Text-fig. 9 show the asci with their eight spores. When the crushed perithecia are stained in cotton-blue in lactic acid, there can be seen the apical perforations of the asci with the two radial thickenings (Text-fig. 9). The spores are much wider in proportion to their length than those of *G. tetrasperma*. They are black, or, in strong light, brown. Some of the spores are remarkably apiculate at one end (Text-fig. 9). The shape of the spores is also shown in Plate III, Figs. 6, 7, 9, 12, and 13. The pitting of the epispore in *G. cerealis* is sometimes closer than

EXPLANATION OF PLATE III

All figures are those of Gelasinospora cerealis

FIG. 1. *A malt agar culture, producing perithecia. Spores which have been shot away are lying on the surface of the agar.* × *10.* FIG. 2. *Perithecia crushed in water.* × *15.* FIG. 3. *Translucent perithecia revealing asci within.* × *20.* FIG. 4. *Perithecium showing structure of wall.* × *30.* FIG. 5. *Section of young perithecium, stained, showing spores and periphyses.* × *30.* FIG. 6. *A group of asci in water, obtained by crushing a perithecium between a slide and coverglass. There are no paraphyses.* × *30.* FIG. 7. *Eight young spores in an ascus. Pits on the spore walls are clearly shown.* × *225.* FIG. 8. *Ripe spore, crushed in water to show pits.* × *600.* FIG. 9. *Young spores showing pits. The upper spore is orientated to show one of the germ-pores.* × *600.* FIG. 10. *Two young spores, the lower of which is abnormal in that it possesses ridges on the spore-wall instead of pits.* × *225.* FIG. 11. *Spores on agar, one of which (centremost of upper three) is germinating.* × *30.* FIG. 12. *Germinating spore which has sent out hyphae from both ends.* × *225.* FIG. 13. *Germinating spore which has sent out a hypha from one end.* × *225.*



Gelasinospora cerealis spec. nov.

in *G. tetrasperma* (*Cf.* Plate II, Fig. 6, and Plate III, Fig. 8). When the spores germinate, some of them produce vesicles from one end only, but most of them produce vesicles from both ends (Plate III, Figs. 12 and 13). The mycelium produces neither macroconidia nor microconidia.

TEXT-FIG. 9. *G. cerealis. Drawing (semi-diagrammatic) of ascus containing eight spores. Near the perforation, at the apex of the ascus there are two radial thickenings. Three of the spores are strongly apiculate. The lowermost spore is turned so that it appears bean-shaped.* × 250.

(2) *The Sexuality of the Spores*

To determine the sexuality of the spores of *G. cerealis*, 18 spores were sown separately on slants of malt agar and induced to germinate. Five days later every one of the 18 mycelia had produced perithecia. Plate III, Fig. 1, represents a monosporous culture which has been growing in a Petri dish for about 10 days, and is producing perithecia. From 18 such cultures it is concluded that the spores produce homothallic mycelia.

(3) *The Number of Nuclei in the Spores*

Using the same method applied to *G. tetrasperma*, sections of perithecia of *G. cerealis* were obtained and stained in safranin and light-green. The spores of *G. cerealis* proved to be less favorable material for cytological examination than those of the preceding species, but very young spores were eventually found which revealed the fact that the spores of *G. cerealis* each contain two nuclei.

Acknowledgments

The investigation was carried out at the Division of Botany of the Central Experimental Farm, Ottawa, where Dr. H. T. Güssow provided all facilities, and gave every encouragement and much helpful criticism. It also gives the writer much pleasure to acknowledge her indebtedness to Dr. G. R. Bisby of the University of Manitoba, for his continued interest and his generous assistance. Two other mycologists to whom she wishes to express her best thanks are Prof. H. S. Jackson of the University of Toronto, and Dr. B. O. Dodge of the New York Botanical Garden.

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